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Applications of basic elements in a theory of individualized instruction to computer-assisted programs in mathematics, reading, and spelling are described and recent results obtained in an existing elementary school facility are reported. To optimize learning in computer-assisted instruction (CAI) a program model is provided in which content, mode, and sequence of current presentation are determined by a child's demonstrated error rate, time to respond, and learning patterns. Reading and mathematics programs following this tutorial model are described together with a detailed review of the curricula and physical characteristics of a system presently functioning in an elementary school. Results at this facility continue to indicate significant achievement differences favoring students exposed to CAI. A new program in spelling, designed to investigate how spelling and similar verbal skills are acquired, is reported and recent experience in the logistics of introducing a CAI system in a rural school district is noted as having indicated no operational problems different from those encountered in urban applications. Listings of recent publications, lectures, and films by project personnel are included. (SS)

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FINAL REPORT

Contract No. OEC-4-6-061493-2089

PROGRAM IN COMPUTER-ASSISTED INSTRUCTION

August 1968

U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

Office of Education
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Program in Computer-Assisted Instruction

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August 1968

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U.S. DEPARTMENT OF
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Summary

Areas of research investigated in this report, which is a supplement to Final Report OE 5-10-050, include the continued development of a computer-assisted instruction program in mathematics and initial reading at the Brentwood Elementary School, a new investigation of computer-based instruction for spelling at Costano Elementary School, and the initiation of a CAI program in elementary-school mathematics for children in rural Kentucky through provision of necessary teletype equipment and drill-and-practice curriculum materials.

Mathematics and Reading

The theory of individualized instruction developed at Brentwood through experimentation with the mathematics and reading programs can, with proper constraints, be generalized to other programs such as elementary science and beginning work in foreign languages. This theory of instruction attempts to optimize the learning situation by manipulating variables such as content, nature and sequence of presentation, to provide the best learning environment for each individual child. To achieve individualization, a means for determining the best future program of instruction for each child based on the history of his past responses was required. Presentation of materials for each child was controlled by correctness of his past responses, the length of time he took to make them, and the nature of his past learning patterns. A more detailed statement of plans of the Brentwood part of the contract may be found in the conclusions given as part of Final Report OE 5-10-050.

Spelling

A new experiment designed to investigate how computer-based spelling should be taught and to gain insight into how spelling and similar verbal tasks were learned was started. Concurrently, techniques for optimal individualization for both lesson content and student feedback to increase the influence of the child's response history on instruction were to be examined.

Morehead, Kentucky

In May 1967, 30 teletypes were delivered to Breckenridge School (a laboratory school at Morehead State University, Kentucky) and 2 teletypes were delivered to Elliotsville School, Morehead, Kentucky. Supporting teletype equipment for both Morehead and Stanford was included. By June 19, 1967, routine on-line drill and practice in elementary mathematics began. There was not sufficient time during the period of the contract to make a behavioral evaluation of student performance. The primary purpose of the project was to attempt the installation of a system such as this in a rural area. Thus, the problem was one of operational rather than behavioral feasibility. The experience of the several months of operation indicated that there were no really different problems encountered in operating in a rural area rather than an urban area. Certainly, the student response was at least as positive, if not more so.

Chapter 1

Introduction

On June 29, 1966, the Institute for Mathematical Studies in the Social Sciences received a contract from the U. S. Office of Education to continue and supplement the work begun under Contract OE 5-10-050. The objective of the first contract was to develop and implement a computer-assisted instruction (CAI) program in mathematics and initial reading. Professor Patrick Suppes continued as principal investigator for the mathematics program and Professor Richard C. Atkinson for the initial reading program. Development of lesson materials for both mathematics and reading and the development of the system continued, each having a decided influence on the other.

Comparing tutorial instruction with the drill-and-practice and the dialogue systems of computer-assisted instruction, the tutorial mode falls in the middle. The drill-and-practice program presents a fixed, linear sequence of problems. Student errors are corrected in a variety of ways (e.g., a prompt response is given in the form of a partial answer, or the entire correct response is furnished following an error). No real-time decisions are made, however, for introducing unique teaching strategies or instructional materials on the basis of a student response. The dialogue system provides the richest possible student-system interaction. The student is free to construct unrestricted natural-language responses, ask questions, and in general, exercise almost complete control over the sequence of learning events.

The tutorial system has the capability for real-time decision-making and instructional branching, contingent on a single response or on some subset of a student's response history. Students follow separate and diverse pathways through the curriculum based on their individual performance patterns. The probability is high in a tutorial program that no two students will encounter exactly the same sequence of lesson materials. Student responses, however, are somewhat limited since they must be chosen from a prescribed set of responses or constructed in such a manner that relatively simple text analysis will be sufficient for their evaluation. The Stanford CAI program in initial reading and mathematics is tutorial in nature.

1.1. CAI as a Tool for Teaching

The theoretical basis of CAI is that immediate reinforcement facilitates learning. The Stanford CAI program provides immediate feedback through reward messages, through the presentation of the next problem, and through "wrong-answer" messages.

When the Stanford-Brentwood CAI project was initiated, the common criticism and fear heard from educators and lay citizens alike was that computers would replace teachers and dehumanize teaching. After the first year of operation, however, the comments gradually changed from those of apprehension and criticism to those of acceptance, because the system demonstrated that it is practical to individualize instruction. If there is any one fact that has been thoroughly established in 60 years of intensive investigation in education, it is that a wide range of individual differences will be found in any classroom on any dimension one wishes to examine. CAI offers the tool for tailoring instructional procedures to these individual differences.

1.2. CAI as a Tool for Research

The two factors that render CAI useful as a tool for research are (a) the control of independent variables; and (b) the detailed response data recorded by the system. Our Laboratory achieved a degree of control of environment and presentation that was impossible heretofore in a classroom setting. The immediate environment of each student's response terminal was precisely the same as every other student's. Chairs and machines were identical for all students. Every picture seen on the projection device, every bit of orthography or other display on the scope, and every audio message which the student heard were specified previously and were standardized or varied as the experimenter desired. This is not to say, of course, that all sources of variation were controlled. The CAI facility did achieve, however, a degree of control equivalent to that of the psychologist's learning research laboratory. Many problems in learning theory which have been investigated rigorously only in a laboratory setting can now be looked at in an on-going school context.

The collection of fine-grained response data is the second capability of CAI which is extremely important for research. For example, each response made by each student was recorded on data tapes. Each response record included a complete description of the response in terms of coordinates taken from the face of the scope or the keys depressed on the typewriter. The response was defined as correct or incorrect; if it was correct, it was categorized according to the type of error made. The response latency was recorded in tenths of a second. The contents of 31 counters and 32 switches associated with the student's past history of performance were also recorded with each response on the data tape.

Testing mathematical learning models in a closer approximation to actual classroom learning than has existed in the past is another important use of CAI as a research tool. Typically, such models have been tested through infra-organism behavior or through contrived tasks, such as paired-associate list learning or probability learning. The kind of sequential response data gathered at the Brentwood facility will be used in the development of optimization models for learning (Groen and Atkinson, 1966;[1] Atkinson and Shiffrin, 1967[2]).

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[1] Groen, G., & Atkinson, R. C. Models for optimizing the learning process. *Psychol. Bull.*, 1966, *66*, 309-320.

[2] Atkinson, R. C., & Shiffrin, R. M. Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory*, Vol. 2. New York: Academic Press, 1968. Pp. 89-195.

1.3. CAI as a Tool for Curriculum Evaluation

The performance data gathered in the CAI system was examined at all levels--from the perspective of overall goals or from the perspective of the various strategies and approaches adopted in the curriculum. Responses to blocks of homogeneous problem types, responses to separate problem types, and responses to the individual problems themselves were examined in great detail. Student performance records were examined to see if a particular section, level, or item of the curriculum was functioning in the manner for which it was designed. It is at this detailed level that CAI exhibits its greatest power for evaluation.

Chapter 2

Methods

2.1. The Population

During the school years of 1966-67 and 1967-68, the first and second graders at the Brentwood School, as well as some kindergarten children and fourth graders, participated in the Stanford CAI Project. The Brentwood School used an ungraded program based on a level system. In 1966-67, there were four first-grade classrooms at Brentwood, two of which (49 students) received instruction in mathematics under computer control and two of which (56 students) received computer instruction in initial reading. All first graders were included in the program. During the year of 1967-68, four second-grade levels (72 students) received computer instruction in mathematics and four first-grade levels (80 students) received CAI instruction in reading. Thus, half of the second graders continued computer-assisted instruction in mathematics for a second year.

2.2. Stanford-Ravenswood School District Cooperative Plans and Teacher In-service Training

A serious attempt, begun in 1965-66, was made by members of the Stanford Project to prepare the teachers and parents of the Ravenswood District, and of the Brentwood School in particular, for the acceptance of the technological innovation of a computer-assisted instructional laboratory. Meetings which initiated intensive interaction between project staff and school district personnel continued throughout the summer of 1966 with a two-week workshop that was held on the Stanford campus for the two teachers who were directly involved in the reading program and continued into the fall with weekly planning groups.

A six-week workshop was held during the summer of 1967, in which four teachers from the Brentwood School, Mrs. Joan Brewer, Mrs. Vera Boyson, Mrs. Louise Ahern, and Mrs. Patricia Nordseth, acted as consultants to develop activities that would coordinate their classroom program with that of the Laboratory.

Weekly meetings, including teachers and project personnel, were held to evaluate student progress on the system and to exchange views and information about classroom and laboratory instruction, and the performance of the students in both environments.

A member of the Stanford staff was placed permanently at the Brentwood School as a school-affairs liaison officer. His duties included the resolution of any organizational problems that arose within the Brentwood School. He also conducted tours for visitors who visited the Laboratory.

The preparation and effort expended to establish school-project cooperation paid off handsomely. The enthusiasm and support of the teachers was highly gratifying. We held many exhibits, open houses, and discussion groups for the parents of the Brentwood School and the patrons of the Ravenswood School District. Again, the support of the parents, the school board, the administration and the teachers exceeded all expectations.

2.3. Description of System

An IBM 1500 CAI system was designed and constructed by IBM engineers in close collaboration with Stanford personnel. The student response terminals consisted of a cathode-ray tube (CRT), a modified typewriter keyboard, a light pen, a film projection device, and a set of earphones with an attached microphone.

The 16 student-response terminals were serviced by an IBM 1800 Process Control computer. This central processing unit had a relatively limited (i.e., 32K) immediate access core storage. Rapid access bulk storage was provided by six interchangeable disk drives; each disk contained 512,000 16-bit words. The audio component of the system consisted of a bank of IBM 1505 audio units. Each audio drive unit was connected to one of the response terminals, but the connections were varied at will. Response data flowing into the system from the student terminals was recorded on two IBM 2402 tape units. An IBM 1501 station control, a 1442 card reader punch and a 1443 line printer completed the configuration of the IBM 1500 CAI system. This configuration is shown in Figure 1.

The IBM 1500 CAI system was a time-sharing system in the sense that activities at each student response terminal were examined in sequence and appropriate actions taken. The time-sharing was not strictly sequential since certain priority conditions within the instructional system could preempt the sequence of programmed instructions.

The entire process moves at a very rapid rate. Subjectively, the student at the terminal feels he has the full attention of the system. The response time for the CRT was less than 1 second and the projector response was nearly as fast. The audio response time was somewhat slower, ranging from 2 to 4 seconds on the average.

The Laboratory was housed in a rectangular, prefabricated steel structure approximately 3,200 square feet in area on the Brentwood School grounds and contained a terminal room, an off-line teaching room, the central computer room, and a group of offices for the Laboratory personnel.

The staff of the Stanford-Brentwood CAI Laboratory consisted of 10 members. The Laboratory was under the general management of a senior programmer who was also in charge of the data reduction staff. His staff included 2 programmers, 2 graduate students and a secretary who also functioned as a receptionist. The systems group was headed by another senior programmer who had on his staff an assistant programmer and a computer operator, plus a technician who handled audio assemblies.

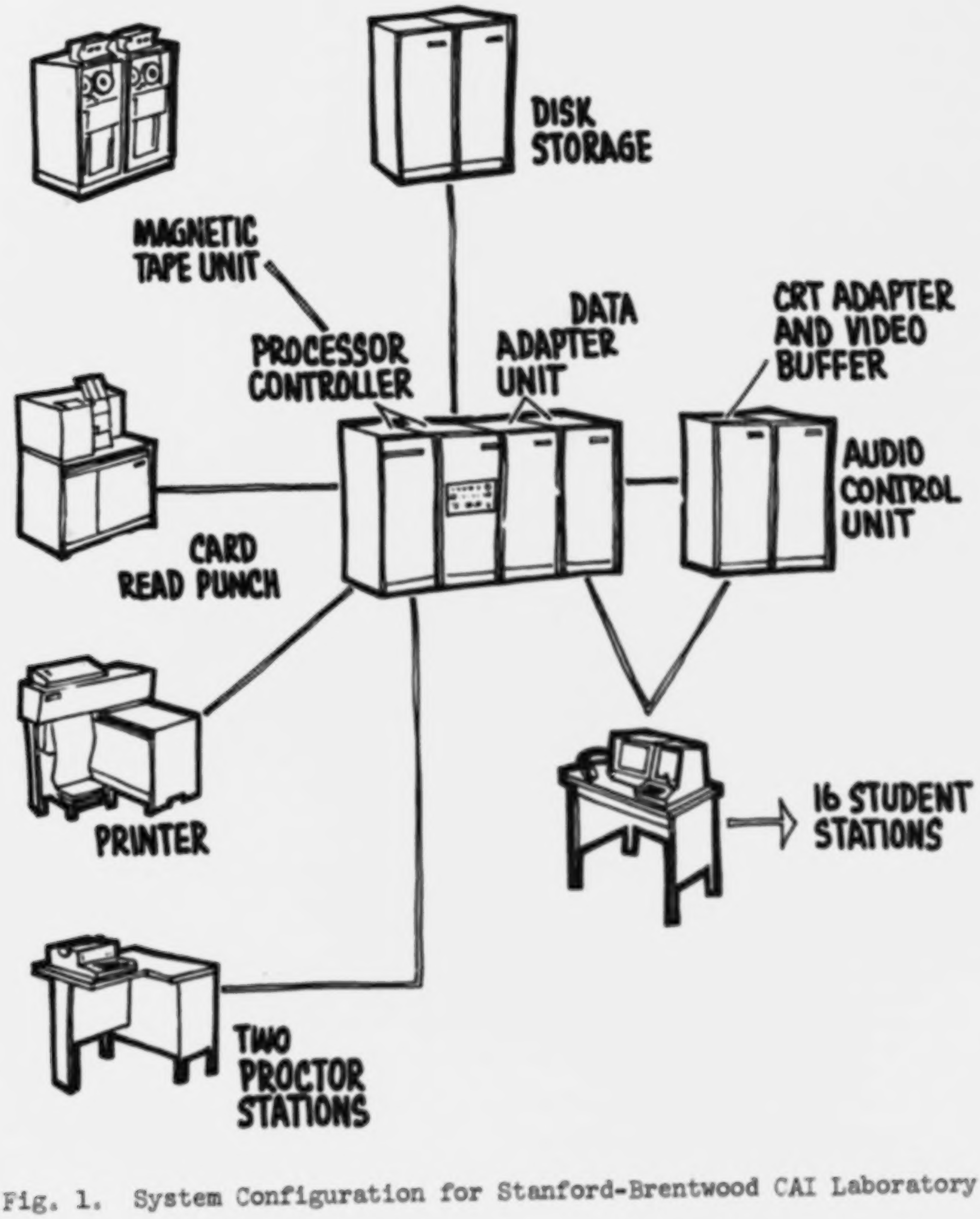
MAGNETIC TAPE UNIT
DISK STORAGE
DATA ADAPTER UNIT
PROCESSOR CONTROLLER
CRT ADAPTER AND VIDEO BUFFER
AUDIO CONTROL UNIT
CARD READ PUNCH
PRINTER
16 STUDENT STATIONS
TWO PROCTOR STATIONS

Fig. 1. System Configuration for Stanford-Brentwood CAI Laboratory

The coding groups for both the mathematics and the reading programs were also housed in the Laboratory. The mathematics and reading coding groups were directed by a senior lesson programmer and consisted of 4 coders, plus part-time debuggers and graduate assistants. Proctors supervised the children in the terminal room itself and were responsible for off-line instruction. IBM also provided several customer engineers who were either on duty at the Laboratory or were on call. The stability of the system ultimately improved so that the customer engineer staff was reduced to a single man during school hours.

2.4. Laboratory Operation, 1966-67

Full-scale operation with the students began on November 1, 1966. The daily schedule is indicated in Figure 2. The starting date was later than originally anticipated, because of a delay in the delivery of the 1500 system which arrived at the Brentwood School on July 10. July 10 to November 1 was devoted to a shakedown and debugging period of the system which was, of course, untested in on-line operation.

Mathematics. On October 3, 49 children from two of the first-grade classes at Brentwood School went to the CAI classroom. Each class was divided into two groups of 10 to 14 children; each group was in the Laboratory for 25 minutes on Monday through Friday afternoons between 12:30 and 2:30 p.m. During this week, preliminary counting tests were given to each child, and it was found that 11 children had inadequate counting skills. They were tutored individually throughout the month of October.

On October 4, 5, 10, and 11, half of each group spent classroom time on the playground with a psychologist (Dr. Rivka Eifermann of the Hebrew University, Jerusalem, Israel) who taught them simple games incorporating the concept of sets, including the empty set. Later in the week, all children were asked the same series of questions about sets to determine whether those who had played the game had a better understanding of what a set was. The results were not conclusive.

During the week of October 21, five children from each group were taken out of the classroom each day for individual testing. The tests, which were designed by the School Mathematics Study Group, were administered by CAI staff, and results were compared with the results obtained by the School Mathematics Study Group in their studies of culturally disadvantaged children.[1]

On October 27, class time for Group IV was divided into two periods of 10 minutes each. Each period half of the group, five children, went into the terminal room for computer-assisted instruction, while the other

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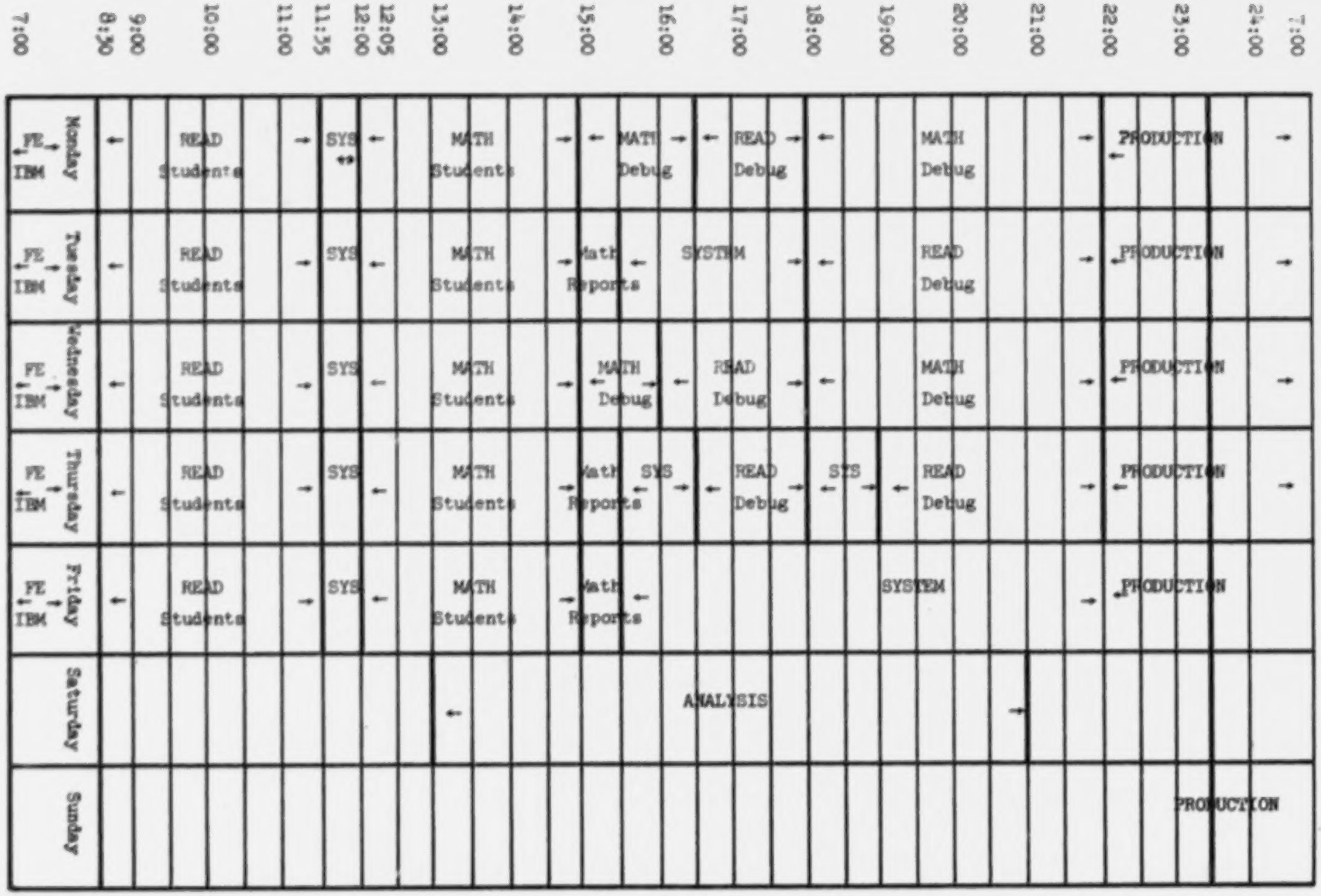
[1] Leiderman, G. F., Chinn, W. G., and Dunkley, M. E. The special curriculum project: Pilot program on mathematics learning of culturally disadvantaged primary school children. School Mathematics Study Group Reports, No. 2, 1966, Stanford University. 132 pp.



Day	7:00	8:30	11:35	12:05	15:00	18:00	22:00
Monday	FE IBM	READ Students	SYS	MATH Students	MATH Debug READ Debug	MATH Debug	PRODUCTION
Tuesday	FE IBM	READ Students	SYS	MATH Students	Math Reports SYSTEM	READ Debug	PRODUCTION
Wednesday	FE IBM	READ Students	SYS	MATH Students	MATH Debug READ Debug	MATH Debug	PRODUCTION
Thursday	FE IBM	READ Students	SYS	MATH Students	Math Reports SYS READ Debug	SYS READ Debug	PRODUCTION
Friday	FE IBM	READ Students	SYS	MATH Students	Math Reports	SYSTEM	PRODUCTION
Saturday				ANALYSIS			
Sunday							PRODUCTION

Fig. 2. Brentwood Systems Schedule (November, 1966)

half remained in the classroom with one of the teachers. In the terminal room, each child was assigned a proctor who helped him get started, and who monitored the entire lesson which lasted from 3 to 5 minutes. All children were faded[1] after the first lesson.

On November 1, children in Groups I, II, and III did the first lesson under the close supervision of a proctor. On that same day the children in Group IV worked from 15 to 17 minutes. The seven proctors did not monitor these children, but observed them as they worked. The children were attentive throughout and did not seem to tire of the work. At the end of the 15 minutes, one child had nearly completed Book 1. During this period, however, proctors detected some errors which were especially confusing to children new to machine work. (In one case, an audio tape "ran away" and played on, independent of the problems being solved. In a few cases, the computer mistakenly identified a correct answer as incorrect.) Because of these errors it was decided that the children should report to the terminal room in groups of 7 or less so that each child could be monitored by one of seven proctors until the error problem was minimized.

On November 7, a regular terminal-room schedule was established. Groups continued to be divided into two 10-minute periods, with seven proctors each assigned to listen with one child. An additional proctor took care of the proctor typewriter and loaded audio tapes at the beginning of the day or whenever a child transferred from one book to another. The fade command allowed each child to finish his lesson and to return to the classroom before the 10-minute period was over.

By November 9, most children could start their lessons without help from a proctor. Those who could not start their program alone usually waited for a proctor's go-ahead, not because they did not know how, but because they either wanted attention or were reluctant to begin without an authority's approval.

If a child failed to meet the established criterion for a lesson, his proctor, responding to instructions typed on the proctor typewriter, assisted him, recording all pertinent information on a special sheet which was turned over to the master proctor at the end of the day. Notes from these sheets were used to inform classroom teachers of each student's progress and as aids for revision of the material.

On December 12, only three proctors were assigned to the terminal room; two proctors provided individual help while a third supervised the entire room and dealt with discipline problems. A fourth proctor's duties included changing audio tapes and dealing with minor systems difficulties. Each child was assigned a permanent station, and the groups were no longer divided into two periods. Seven to 10 children worked on-line from 12 to 15 minutes; fade time was standardized by the clock to assure that all children were back in the classroom by a specified time. Two to 4 children remained in the classroom each day on a rotating basis, thus allowing more time and space for valuable classroom instruction and activities. The revised schedule proved satisfactory for both the proctors in the terminal room and the classroom teacher.

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[1] The FADE command, which is input by a proctor, caused a student station to be signed off as soon as the student completed the current lesson.

Reading. During the period from the opening of school in September to mid-October, the program of pretests begun in the spring was completed by Dr. Lucille Mlodnosky.

The students began going to the Laboratory on a daily basis on November 1. During a week of orientation in the off-line teaching room, the students were acquainted with the use of the earphones, microphone, and light pen. Exercises and games were used to familiarize them with the equipment and the kinds of learning tasks they would encounter in the terminal room. During the second week in November, they were introduced gradually to the actual response terminals on a staggered basis; that is, a lesson in the terminal room was followed by a lesson in the off-line teacher room. By November 15, the students were on the system daily for a 20-minute instructional period. During these early exposures to the terminal equipment, an adult was stationed behind each child to assist him with problems in handling the equipment. The children were adapted quickly to their new environment, and the adults were gradually withdrawn. By mid-November, the proctor staff within the terminal room consisted of one teaching proctor, one machine proctor, and a remedial-reading teacher.

The students went to the Laboratory in four groups, since the terminal room was equipped to accommodate only one half of a normal classroom at a time. Each group was given 20 minutes of instruction. A minimum 10-minute interval was scheduled between groups to prepare the system for the next group. Each student was signed-on at a response terminal, and the appropriate films and audio tapes were loaded into the projectors and audio-drive units. When the sign-on process was completed, the name of the student assigned to a given terminal appeared on the CRT.

As each group arrived at the terminal room, the students entered the room, seated themselves before their assigned terminals, put on their earphones, touched their names with the light pen, and began the lesson. During the instructional session, the machine proctor was stationed at a proctor's typewriter that transmitted messages from the central system. These messages consisted primarily of identification of a system or terminal failure, transfer of a student from one lesson to the next, or notification of an error limit exceeded at some terminal. In the case of a system or terminal failure, the machine proctor took appropriate action, which ranged from transferring a student to an empty terminal to notifying the head systems programmer. When a student transferred to a new lesson, the machine proctor changed his audio tape. Each block of problems within a lesson had an error limit of 50 per cent of the total number of problems within the block. If the error limit was exceeded by the student, notification was transmitted to the machine proctor, who in turn conveyed the information to the teaching proctor.

The teaching proctor observed the student and chose between two courses of action. If the difficulty appeared to be mechanical (e.g., incorrect use of light pen) or a minor misunderstanding of directions or lapse of attention, the teaching proctor signed on the terminal with the student and helped him through the troublesome section. By signing on the terminal, a proctor bit was set in the response record to identify responses which were not necessarily those of the student. If, however, the student's difficulty appeared to be of a serious nature, the proctor removed the student from the terminal and transferred him to the remedial teacher for diagnosis and personal instruction in the off-line teaching room. Fortunately, during the entire year's run the necessity for such off-line instruction was infrequent. The remedial-reading teacher functioned primarily as an assistant to the teaching proctor within the terminal room and was brought into play in her major function only when the system was down or an individual terminal failed.

The population of the first-grade classroom was somewhat smaller than anticipated, which left terminals unoccupied for each of the four groups. During the early phases of the program this arrangement was fortuitous since spare terminals were available in case of terminal failure. After Easter vacation, however, the stability of the system improved enough so that it was no longer necessary to maintain a large number of backup terminals. Remedial second-grade students then were run on the newly available terminals. The second-grade teachers reported a definite increase in interest and application to the reading task of the remedial students within the classroom.

2.5. Laboratory Operation, 1967-68

Mathematics. On September 18, a staggered-day schedule began in the primary grades, and students reported to the Laboratory for mathematics instruction. Two days were spent testing and establishing routines and schedules, and on September 20, the students started the programmed lessons.

By September 29, after eight days of CAI instruction, the fastest child had completed 5-1/2 books (62 lessons), while the slowest child had completed 2 books (25 lessons).

Reading. On September 18 and 19, 1967, 79 Brentwood first-grade students were introduced to computer-assisted instruction in initial reading. While a remedial teacher worked with the remaining children, 2 students worked at a student terminal using the light pen and earphones. All children were familiar with the terminal equipment by September 20, when they began work on Days 1 and 2, the introductory lessons.

Proctoring procedures were modified as the need for adult supervision in the terminal room on a one-to-one basis diminished. Only three adults were present in the terminal room: the head proctor, the machine proctor, and an on-line proctor. In addition, a certified remedial teacher was always present in the teaching room of off-line remedial work.

On September 25, the students began Day 3, which consisted of Read I-93 and I-94, the letter-teaching lessons. On September 29, after the first week of instruction, the students were distributed as follows:

Lesson	Number of Students
Day 3	42
I-01	24
I-02	10
I-03	3
	79

Chapter 3

The Curricula

3.1. Mathematics

The 400 lessons in the first-grade mathematics program covered the ordinary range of first-grade arithmetic topics, such as counting, numerals, addition, subtraction, and linear measure, as well as a few topics less commonly found in first grade, namely, sets and set notation, and congruence of plane figures. The content and scope of the curriculum were drawn largely from Sets and Numbers, Book 1 by Patrick Suppes,[1] with the addition of some topics, such as oral story problems which cannot, by their nature, be adapted to a textbook format.

Since the programmed lessons were tutorial, many of the lessons were explanatory, relying on oral explanations synchronized with changing visual displays. The average lesson contained fewer than 10 problems, and explanations were simple and direct. Generally, the problems within one lesson were all of the same type; the first few were accompanied by explanatory audio messages and the remainder were practice problems.

Both explanatory and practice problems contained provisional audio messages which were heard only by students who responded incorrectly or failed to respond within a reasonable time. As an example, for the first problem in Lesson 6GL, the data showed that 44 out of 49 students chose the correct answer. Three students made no response within 20 seconds and heard, "Which set below has two members?" The two students who responded incorrectly saw a sad face and heard the audio message, "Point to the box next to the set with two members." After this negative reinforcement routine, they were given a chance to respond again, and both responded correctly.

For this problem, as for most problems throughout the curriculum, students were allowed three chances to produce the correct answer. After three incorrect responses, the correct answer (or an arrow pointing to the correct choice) was displayed, accompanied by a brief audio message. Moreover, a 20-second time limit was set for every problem, and when that limit was reached, an additional hint was given. If a student did not respond within 40 seconds, the answer was displayed. In any case, the student was required to make the correct response before the program continued to the next problem.

Lesson 6GL was taken by 49 students with 41 to 46 initial correct responses on the 13 problems. As was to be expected, problem 2 (the empty set) was the most difficult since it had no accompanying oral instruction. The average response time was 6 seconds, and no student failed to respond within the 40-second time limit.

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[1] Suppes, P. Sets and Numbers, Book 1. New York: Singer, 1965.

For the practice problems, the last nine problems of the lesson, the number of initial correct responses made by each student was accumulated and compared to a preset criterion. In this lesson, the students were expected to answer 7 of the 9 problems correctly (other possible criteria: 5 out of 6, 6 out of 8, 8 out of 10, etc.). As soon as a student made the required number of correct responses (in this case, 7), he was allowed to skip the remaining problems and to begin the next lesson. On the other hand, if a student missed any three of the nine problems, he clearly failed criterion and was branched immediately to the remedial lesson, bypassing remaining problems in the lesson. In Lesson 6GL, there were four students who failed to meet the 7 out of 9 criterion. They received immediate remedial material in the form of a lesson containing the same kinds of problems, but with a slower development of the ideas using simpler vocabulary and sentence structure.

Later in the year as the concepts of counting and addition were assimilated, students were required to give constructed responses using the keyboard. Slightly more than one fourth of the lessons required typed responses. Regular drills with problems of varying degrees of difficulty were provided. In order to adapt the curriculum to individuals, the drills were usually written on five levels of difficulty with branching decision based on individual records. The lessons were grouped in books containing from 9 to 34 lessons.

The amount of material contained in remedial branches was a major factor in the rate of student progress through the curriculum. With the exception of several children who entered school late in the year, all students began programmed instruction in Book 1 on October 27, 1966. Table 1 shows the books in which students were working at the end of the school year.

TABLE 1

Book No.	10	17	18	19	20	21	22	23	24	25
No. of students	1*	7	5	4	12	2	10	3	6	2

*This student received classroom instruction during the latter part of the year.

Content of programmed lessons. The topics covered included the following:

1. Sets. Concept of a set and member of a set, description of sets by naming a common property, description by enumeration, use of set braces, empty set, equality of sets, union of sets, solving set equations, equivalence of sets, use of N-notation as a pro-numeral, construction of equivalent sets, difference of sets, subsets.

2. Numerals and counting. Numeral recognition, counting objects in arrays, counting randomly arranged objects, counting members of sets using N-notation, successor, predecessor, counting by two's, counting by five's, counting by ten's, counting by ten's and one's, place value, place value related to dimes and pennies, more and less, number line, oral story problems.

3. Addition. Concept of addition using N-notation, equations, column addition, commutativity, three addends, solving addition equations (one missing addend), construction and use of addition tables, oral story problems with and without pictures to count.

4. Subtraction. Concept of subtraction as "take-away," equations, column subtraction, subtraction as the inverse of addition, oral story problems.

5. Geometry. Recognition of figures (square, circle, triangle, rectangle, line segment), concave and convex, open and closed, inside and outside, congruence with rotations and reflections, similarity with rotations and reflections, construction of rectilinear figures given vertices, counting sides and vertices, linear measure.

6. Games. "Reward" games used primarily for motivation.

7. Miscellaneous. Ordinals, liquid measure, time, readiness for fractions, number words.

Classroom work. The activities carried out in the classroom included: (a) use of physical objects to introduce concepts presupposed by the programmed lessons; (b) work originally planned as programmed lessons; (c) remedial work for individual children; and (d) enrichment material for individual or groups of children. A discussion of classroom activities follows.

Introduction of concepts presupposed by the programmed lessons. From September 30 until the first group began programmed instruction on October 27, the four different groups met in the Laboratory classroom each day for approximately 20 minutes.

The activities carried out in the classroom were intended to give the children a variety of manipulative experiences which the programmed lesson presupposed. At the same time it was important to exercise care that no tasks introduced in programmed lessons were first introduced in the classroom setting, since this would make meaningless any data collected from the programmed lessons.

We began by doing exercises in one-to-one correspondence. (Since knowledge of counting was to be tested during the first month of school, reference to number in this exercise was strictly avoided.) An example of the kind of activity done was to hold up a given number of pencils and to instruct the children, "make yours look just like mine." The terms "as many as" and "the same number of things as" were also introduced.

The tasks ranged in complexity from the simple task of matching like objects one-to-one through three intermediate stages to matching pictures of unlike objects one-to-one. The amount of practice necessary at each of the intermediate stages was determined to a great extent by the children's ability or lack of ability to count. (Though no mention of counting was made, those children who already knew how to count immediately chose this method of solving their problems.) When three or fewer objects were involved, mistakes were uncommon. When four or five objects were involved, errors increased, and when more than five objects were involved, errors were quite common. Methods of correcting or verifying answers were devised by the children.

These activities led to a development of the concepts of more and less. Few children had any difficulty with the concept of more, but almost every child had trouble with less. The word "less" seemed completely unfamiliar to many children, and even when stressed as being the opposite of "more" or as meaning "not as many as," "less" was the most difficult word introduced to the children.

Another concept the children needed to understand in order to do some of the programmed lessons was that of giving yes or no answers to questions. As might have been expected, questions requiring yes answers were quite easy, while those requiring no answers were considerably more difficult.

Exercises using the words top, middle, bottom, before, and after were given, since knowledge of these words was presupposed in some of the machine lessons. There was little difficulty with these words in the limited contexts in which they were used.

After the children had been tested, they were introduced to counting through 5, and later to counting through 9. There was considerable discrepancy in the abilities of most children to rote count and in their abilities to "Show me seven blocks," or to give an answer to "How many blocks do I have?" The slower children required a period of several weeks to develop their ability to count to 9.

The more advanced children were able to generalize that (a) we need 1 more to make the next number; and (b) a number is 1 more than the number before it. Many exercises in completing patterns were necessary before those generalizations were made.

The children also worked on concepts of the same, more, and less when comparing two groups of objects. All of these activities were done using manipulative materials.

Sets of objects were introduced, as was the concept union of sets. Both topics were introduced using manipulative objects, and no notation was used in these exercises. Considerable attention was given to identifying sets as having particular properties in common, leading up to identifying sets with the same cardinality. The children had no difficulty with the concept of the empty set, as long as it was referred to as "the set with nothing in it." The word "empty," however, was unfamiliar to almost all these children, and seemed to be a somewhat difficult one for the children to learn. Thus, reference to "the empty set" increased the difficulty of tasks involving the empty set.

Linear measure was introduced in the classroom, first using non-standard units, and later using standard units. Most of the children had no idea of how to make a linear measurement.

Telling time to the hour, recognizing various coins, and counting money were also introduced in the classroom.

Considerable attention was given to writing the numerals, and late in the year, to writing number sentences. In general, the writing of number sentences was done in connection with story problems given orally.

Work originally planned as programmed lessons. Several times during the year, children remained in the classroom while further programmed lessons were prepared.

During one such period, the groups worked on addition, since this had just been introduced by programmed lessons. The introduction was without any direct reference to manipulative objects, and most children were having considerable trouble. The classroom activities were concerned with using manipulative objects to illustrate addition, and with relating such manipulations to the symbols. The obvious need of children to count in order to solve addition problems led us to provide a wire with 10 beads for each child to use either in the classroom or at his terminal. As the children learned the various combinations, they used the beads only for those combinations they still did not know.

We also played a number of games leading to providing the missing addend. As long as the games were played orally without showing the addition sentence, almost every child could answer correctly. When the number sentence was written on the chalkboard to be read by the children, however, errors increased dramatically. This was true even for those children who could read the equations. Apparently they still were not comfortable relating written symbols to physical experiences.

At another time it was decided that the topics in Books 11, 12, and 13 should be taught in the classroom, while succeeding books were being programmed. Topics included in this classroom work were (a) more addition (both $a + b = \_\_$, and $a + \_\_ = c$); (b) number sequences; and (c) introduction to the number line.

Remedial work. The most frequent topics for which children were sent to the classroom were addition and subtraction. Throughout the year, whenever a child had excessive difficulty with a topic he encountered in programmed material, he was sent to the classroom for remedial work. The time spent with a teacher varied from a few minutes to several days, depending on his needs.

Enrichment work. At various times throughout the year, individual children or entire groups were in the classroom because of machine failures. So as not to interfere with data collection for topics presented in programmed material, enrichment work was provided. One such enrichment unit was in constructive geometry in which approximately half the children learned to manipulate a compass and straightedge. They also learned to read and follow directions for making some simple geometric constructions.

Other enrichment topics were extensions of subjects presented in programmed lessons, such as sets, patterns, and sequences. Game approaches were employed in the enrichment work for these topics.

3.2. Reading

It is assumed that the English-speaking child brings to the initial reading task a relatively large vocabulary and at least an operational knowledge of English syntax. He has a knowledge of the language that enables him to communicate with his peers and with adults; therefore, the primary goal of initial reading is not to teach the language, but to teach the orthographic code by which our spoken language is represented.

In attempting to teach a code, the most reasonable approach is to begin not with all the irregularities and exceptions, but rather with the regular and consistent patterns. This position is not unique to the Stanford Project. It has been advocated by linguists for some years (Bloomfield, 1942;[1] Fries, 1963[2]) and has been implemented in several "linguistically oriented" reading series. The sequencing of monosyllabic patterns as shown in Table 2 and certain extensions and refinements of the basic notions, as stated by the above-mentioned authors, constitute the original work in curriculum design carried out by the Stanford Project.

Description of the reading curriculum. The curriculum was divided into four broad areas of concentration: (a) decoding skills; (b) comprehension; (c) games and other motivational devices; and (d) review. The lesson material and teaching strategies will be discussed briefly for each area. Figure 3 shows the block-level flow chart for Level III, Lesson 9.

3.2.1. Decoding Skills

Letter teaching. The 26 letters were taught in three sets of nine letters; the third set contained a repetition of one letter from one of the preceding sets. The first set of nine letters was taught just prior to Level I, Lesson 1, and contained the nine letters used in the

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[1] Bloomfield, L. Linguistics and reading. Elementary English Review, 1942, 19, 125-130.

[2] Fries, C. Linguistics and Reading. New York: Holt, 1963.

TABLE 2

Reading Curriculum Lesson Sequence

LEVELS	vc	cvc	ccvc	cVce̸ ccVce̸ cccVce̸	cV ccV	cvcc ccvcc	cvvc ccvvc	cvv ccvv cccvv	cccvc cvccc
I 13 lessons	ac	cac							
II 19 lessons	ic	cic	ccac						
III 23 lessons	ec	cec	ccic	cAce̸ ccAce̸	cA				
IV 29 lessons	See Note 2.								
V 23 lessons	oc	coc	ccec	cIce̸ ccIce̸	cI cY cE ccY ccE	cacc			
VI 36 lessons	See Note 2.						ai oo ight	ay	
VII 43 lessons	uc	cuc	ccoc	cEce̸ cOce̸ ccOce̸ cUce̸ ccUce̸	cO ccO	cicc cecc ccacc ccicc ccecc			a ccc i c a e c i ccc e
VIII 65 lessons	See Note 2.		ccuc			cucc cocc ccucc ccocc	ow oy ee ie ea ei ew		o cccuc cuccc o

Note 1: c = any consonant; v = any short vowel; V = any long vowel.
Note 2: Less frequent and less regular variations of preceding patterns (e.g., post-vocalic r, w).

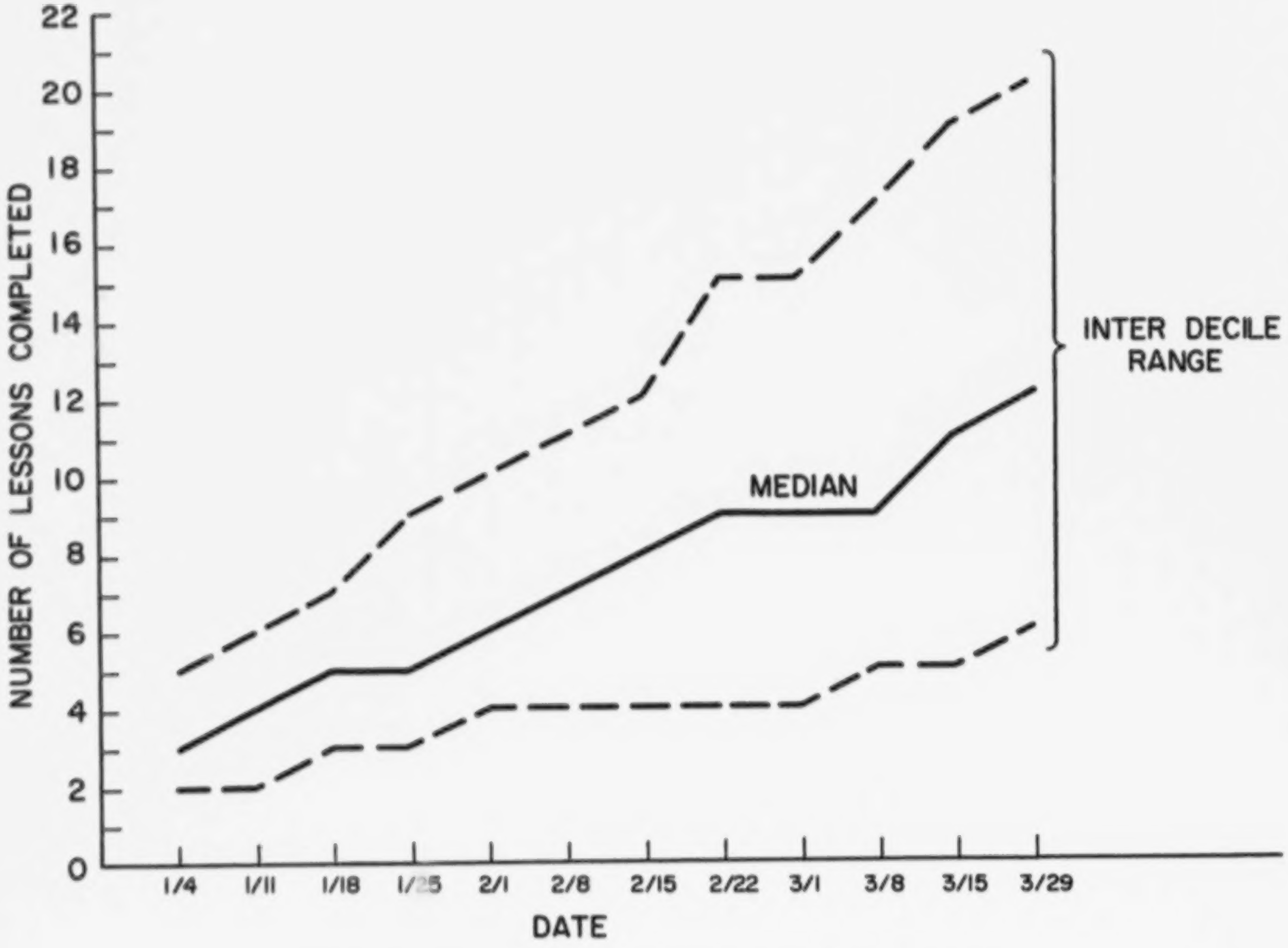

Fig. 3. Cumulative Number of Reading Lessons Completed Each Week for Current Reporting Period

first five lessons. The second set was sequenced between Lessons 5 and 6 of Level I, and the third set appeared just before Level II, Lesson 1. The three sets were constructed as follows:

$$S_1 = \{h, c, t, n, s, a, m, f, d\}$$

$$S_2 = \{g, i, v, p, w, j, b, r, l\}$$

$$S_3 = \{o, x, z, k, e, q, u, y, g\}.$$

Each set was broken into six subsets of three letters. Each subset was called a list $(L_{n1}, L_{n2} \ldots L_{n6})$ and had the following characteristics:

$$L_{n1} + L_{n2} + L_{n3} = L_{n4} + L_{n5} + L_{n6} = S_n.$$

$$\left.\begin{array}{l} L_{n1} \\ L_{n2} \\ L_{n3} \end{array}\right\} \quad \text{Each contains three elements of } S_n \text{ with maximal visual differences.}$$

$$\left.\begin{array}{l} L_{n4} \\ L_{n5} \\ L_{n6} \end{array}\right\} \quad \text{Each contains three elements of } S_n \text{ with minimal visual differences.}$$

For example: $L_{11} = \{h, c, t\}$

$$L_{12} = \{n, s, a\}$$

$$L_{13} = \{m, f, d\}$$

$$L_{14} = \{c, a, d\}$$

$$L_{15} = \{n, h, s\}$$

$$L_{16} = \{t, f, m\}.$$

Minimal audio differences were avoided, and this restriction was an overriding consideration in constructing each list. For example, by the rule of minimal visual differences, L_{15} should have been $\{n, m, h\}$, but the audio confusion of $\{m\}$ and $\{n\}$ had to be avoided.

Each list was taught in a paired-associate paradigm as in the following example: $\boxed{h\ c\ t}$ appeared on the CRT, and the student was requested to touch h. After the student responded, a smiling or frowning face appeared, depending on whether the response was correct or incorrect. An arrow was displayed over $\overset{\downarrow}{h}$, and the student heard the audio message, "This is h."

The order of the three letters was randomly changed on the CRT, and the cycle was repeated for another letter. Three responses (i.e., one response to each of the three items) constituted a trial. The order of response requests was random for each trial.

Criterion was set at two successive errorless trials. The probability of achieving criterion by guessing was approximately 0.001. When a student met criterion, he branched to the next list.

A limit of 20 trials was set for any one list. If criterion was not met within 20 trials, the student branched to a same-different task, using the same list. Again, once through the list was considered a trial. Criterion in this task, however, was three errorless trials. The probability of reaching criterion by guessing was approximately 0.002. If criterion was met, the student branched to a match-to-sample task on the same list. If criterion was not met within 20 trials, a proctor call was given, and the student was taken off the system for remedial instruction in the off-line classroom.

The match-to-sample task differed from the original task only in that the letter to be identified was displayed on the projector screen.

Projector	Scope
h	c h t

Criterion was two successive correct trials with a limit of 20 trials. If a student failed to meet criterion in the match-to-sample task, he was taken off-line for work in the remedial room.

If a student met criterion on the match-to-sample task, he made a second pass through the main-letter identification task. Failure to meet criterion on this second pass placed the student in the off-line room for further remedial instruction.

Each list (L_{11}, L_{12} ... L_{36}) was accompanied by the two types of remedial loops, and successful completion of each list was prerequisite for continuing with the regular lesson material.

If a student failed criterion in off-line instruction, he was referred to the classroom as unready to benefit from computer-assisted reading instruction. The student was returned to the Laboratory when the teacher felt he had reached the proper level of readiness and began work at the letter task where he had failed in the original exposure.

Word-list learning. This section may be described as a set of paired-associate tasks where the stimulus is the verbal pronunciation or pictorial representation of a word (or both), and the response is the correct identification of the appropriate written word in a list of written words. The lists for any given lesson were composed of words generated by the rhyming and alliterative patterns presented in that lesson.

Quantitative learning models, appropriate to the paradigms in this section but similar in nature to those existing for classic paired-associate learning (Atkinson, Bower, and Crothers, 1965)[1] were developed to describe acquisition processes and to assess the effects of learning and forgetting.

Five problem types (PT) containing approximately six problems each were included in this section. Each PT represented a step in a cue-fading technique. The five PT's were:

PT 1 - Cues: picture, orthography, and audio;

PT 2 - Cues: picture and audio;

PT 3 - Cues: audio only;

PT 4 - Cues: picture only;

PT 5 - Criterion test. Cues: audio only.

The student responded to a set of cues by touching a word in a list of words on the CRT. Each student response received immediate feedback. If a response was correct, it was reinforced. If it was an error, the correct answer was indicated by an arrow, and an overt correct response was required before the next problem was presented; otherwise, the student branched to appropriate remedial problems. This is a general teaching strategy followed throughout all the lesson materials, except in the case of the criterion tests. PT 5 was a criterion test and was similar to PT 3, except that no feedback or correction was given on the first presentation of the list. If the student met criterion on the first cycle, he left the word-list presentation block. If he did not meet criterion, he returned to the task described in PT 2, branched past PT 3, and was presented with those items in PT 4 which he missed in PT 5. He then made a second cycle through PT 5 with correction and optimization to one initial correct response for each item.

3.2.2. Comprehension

Producing the appropriate verbalization when confronted with some orthography (decoding or word-attack skills) is a necessary component but not a complete definition of reading. An equal and ultimately more important aspect of reading is "comprehension." Although a great deal has been written about "reading comprehension," it is not at all clear what we mean by the term. The general approach in current reading materials and reading achievement tests is at the paragraph level and primarily employs practice in recall or identification of specific details and sequence of events, and in identifying the "main idea."

While using the standard techniques, we tried to look at the question at the sentence level. Although we make no claim of achieving a complete definition of the field, we advanced three propositions as necessary components for such a definition. To be sure a sentence was understood, it had to be demonstrated that there existed (a) an appropriate set of semantic associations for each lexical item in the sentence; (b) an operational knowledge of syntax; and (c) the ability to identify the lexical items in the sentence which convey a given piece of information.

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[1] Atkinson, R. C., Bower, C. H., & Crothers, E. J. An introduction to mathematical learning theory. New York: Wiley, 1965.

3.2.3. Games and Other Motivational Devices

Rhymes. Rhymes were sequenced into a lesson as a listening activity to help the child develop competency in the discrimination of the rhyming and alliterative sounds of words and to demonstrate to the child the rhythmic use of language.

Games. The games sequenced into each lesson primarily to encourage continued attention to the lesson materials were similar to those played in the classroom, and terminology was used that was common to game-like situations, such as baseball or bingo. In addition, each game was structured to reveal any developing linguistic competency on the part of the child. For example, one game centered on the child's ability to identify a given string of letters when presented in a concept-identification paradigm. The question of how children come to see orthographic commonalities is relatively unexplored, and the game was intended to provide some basic information. Moreover, games gave the children added practice on the sequenced vocabulary. All of these games were intended to provide the children with an intrinsic motivation to continue practicing much of the same material previously presented. Ordinarily the words found in the games were introduced in the preceding lesson. Again, it is to be noted that the responses in the game sections can be analyzed just as paired-associate items or as concept-identification items in more controlled psychological experimentation.

3.2.4. Review Lessons

The reading lessons contained two types of review. A continuous review is inherent in the learning materials which were sequentially introduced in a given lesson and subsequently incorporated in the activities of succeeding lessons. For example, words introduced in list and matrix exercises in Lesson N were reviewed in the sentence initiator and story materials of Lesson N+1. A more conventional type of review was furnished also by review lessons, which appeared approximately every seventh lesson. Vocabulary and concepts previously introduced were re-presented, but in different formats.

The nature of the review lessons varied as the vocabulary and skills of the student progressed. In Level I, the review lessons consisted primarily of straightforward matrix review; that is, the words introduced in the preceding five to seven matrices were reordered and presented in new matrix formats. The review lessons of Level II focused primarily on the recently acquired vocabulary items, prepositions, and the inflectional concepts of the plural-s, third person singular-s, and the -ing suffix.

In Level III, the range of activities in the review lessons was considerably increased and basically furnished the format for review lessons in the succeeding levels. Exercises on phonetic discrimination, word meaning, form class, English-word order, rhyming exercises, analysis and synthesis of words, picture-sentence comprehension, compound and polysyllabic words, and verb forms were included.

Lesson production. An overall design of scope and sequence for the decoding aspect of the curriculum was developed during the first year of the project and was based on the psycholinguistic propositions stated above. The overall design was the primary responsibility of the principal investigator, the senior research associate, and the staff linguist. It must be emphasized, however, that at every stage in the development of the curriculum the intuitions, experience, and expertise of the entire staff played a major role.

A well-defined sequence of presentation of linguistic patterns was a necessary preliminary to actual lesson writing. The development of such a sequence, however, was a dynamic process which involved a complex interaction of study, deliberation, experimentation, and evaluation.

3.3. Curriculum Implementation

After a lesson for a computer-assisted instructional course had been written, many additional steps were necessary before the lesson was ready for use. The major steps in curriculum implementation were audio preparation, film preparation, and coding.

Audio production. The first step in producing audio tapes was to number individual audio messages after the lessons received a final editing. The numbering of audio messages was necessary, since the coders referred to the messages only by number when coding the lessons. As the messages were numbered, an indicator [X] was placed at each point in the message where a display change on the projector or CRT had to be made in order to synchronize with the audio. These display changes most commonly involved the addition or deletion of an arrow or an underline to an existing display, hence the X's were called emphasis indicators.

The messages were numbered in blocks of 50 to facilitate future editing or revisions. The message code number consisted of an alphabetic character followed by two digits and identified uniquely 1,300 messages for each lesson. In practice, the average lesson contained approximately 400 messages.

After the messages were numbered by the coders, the master narration tape was recorded on an Ampex PR-10 two-track tape recorder. The messages were recorded on the "A" channel using an LTV 1800 cardioid microphone. A constant 400-cycle tone was recorded on the "B" channel in conjunction with each message from a Hewlett-Packard 200 AB oscillator controlled by a tone key.

The requirements of the system specified that the 400-cycle tone had to be generated by depressing the key at least 0.25 seconds before the message was started and had to continue for at least 0.25 seconds after the message was finished. Further, the intermessage gap had to last a minimum of 3 seconds and no more than 10 seconds. Also, the emphasis indicator had to be signaled by a cessation of the tone for at least 0.5 seconds and no more than 1.5 seconds.

Practical consideration of audio consumption at the student terminals required that the above-minimum specifications be followed as closely as possible. The recording narrators were required to exhibit pleasant voice quality, clear enunciation and good intonation patterns, and to develop considerable skill in the use of the tone key.

The master narration tapes were produced in a soundproof recording studio at Ventura Hall on the Stanford campus. The master narration tape for each lesson was edited and corrected by the narrator immediately after recording. The tapes were then given a final edit to verify correctness of the messages, clarity of enunciation, proper tone signal overlap, and accuracy of the emphasis indicators. The rather elaborate and painstaking editorial procedure was a vital part of audio production, since correction of tapes was very difficult once they reached the audio assembly process.

Audio assembly. After the master narration tape received the final editing by the narrators, it was sent to the Brentwood Laboratory for generation of a master four-track machine tape. The first two tracks contained audio messages taken from the master narration tape, the third track was reserved for on-line student recording, and the fourth track contained the tape segment addresses.

A machine master was produced by a computer program which read the tone signals on the master narration tape, evaluated the length of a set of such signals, and recorded their associated verbal messages on the machine master using an optimal packing strategy.

Verbal messages of varying length were recorded on the two message tracks in a manner that maximized the number of messages per unit length of tape and minimized the distance between any two messages. The latter condition also minimized the search time required for positioning any message.

The result of the optimal packing strategy was a non-sequential ordering of messages on the machine master. To control an otherwise chaotic condition, a table was generated concurrently with the recording of the messages which specified the location on the machine master, by track and segment number, of the beginning of each message, its sequential number on the master narration tape, and its length. This table, the Audio Symbol Table, was stored on the symbol table disk for each lesson. A printed audio symbol table was also produced for use by the programmers in the debugging process.

The complete process of producing a master machine tape and the associated tables, known as audio assembly, was performed during production hours, typically between 12:00 p.m. and 8:00 a.m., by a single computer operator.

Art production. Production of the art work for the reading curriculum began with the lesson writers who, in the course of writing the lessons, specified the necessary illustrations. Illustrations were required for the word-list sections, some sentence analysis sections, and for all of the listening and reading stories and poems.

A serious attempt was made to include a balanced distribution of racial and ethnic figures in the pictorial illustrations as a reflection of the mixture of those elements in American society. All racial and ethnic types were featured as central figures engaged in interesting activities by means of artistic, socially honest, and appropriate drawing. The illustrations were photographed in blocks of lessons at the Hospital Laboratory of the Stanford Photo Service with a 16mm movie camera and single-frame exposure.

Correct sequence of illustrations was critical; therefore, the art editor, who originally assembled the plates, was on hand to assist the photographer at every shooting session. The plates were shot in blocks of lessons with nine blank frames left between blocks to minimize the difficulty of splicing if later corrections or additions became necessary.

Coding. Before the lessons could be used in the CAI system, they had to be translated into a language understood by the computer. First, the lesson programmers coded the lessons in Coursewriter II, a CAI source language developed by IBM. A coded lesson consisted of a series of Coursewriter II commands which caused the computer to display and manipulate text and graphics on the CRT, position and display film in the projector, position and play audio messages, accept and evaluate keyboard and light-pen responses, update the performance record of each student, and implement the branching logic of the lesson flow by means of manipulating and referencing a set of switches and counters. A typical reading lesson required 9,000 Coursewriter II commands for its execution.

Thirty counters used to keep track of a student's performance were available to the lesson programmer. During the instructional flow, the current values of these counters were used to make branching decisions of what stimulus materials to present next. For example, if the correct-answer counter for a particular class of problems had a high value, the student branched ahead to more difficult topics; a low value branched him to remedial work. These counters contained any number from 0 to 32,767. They were normally set at zero at the beginning of a course and supplemented when desired. For example, counter 4 (C4) recorded overtimes; each time the time limit was exceeded, one was added to counter 4 (AD 1/C4).

Thirty-two switches in either the zero or one position were available to the instructor and kept track of previous events. For example, at the beginning of a problem, zero was loaded into S1 (the "error" switch), which meant no error had yet been made on that problem. If the student made an error on the problem, one was loaded into S1. If a correct answer was made on his second try, the command branched around, adding one to the initial correct answer counter because the error switch (S1) was equal to one.

Many features of the CAI system are not demonstrated by the simplified example presented here, for the pattern of the problems may vary widely from this sample. At various points in a lesson, criteria may be set which, if not met, may branch the student to remedial problems or call the proctor. Parts of the CRT display may be underlined or displayed in synchronization with the audio messages.

While a student was on the system, it was possible for him to complete as many as 5 or 10 problems per minute of the type shown above, providing a significant amount of coded lesson material for student use was not a major problem. Typically, the reading program material was presented in blocks with problems similar in format but different in certain specified ways. Many problems differed only in (a) film display; (b) word display; (c) problem identifier; (d) the three audio numbers; (e) row display of "→" (correct-answer row); (f) correct-answer area; and (g) correct-answer identifier. This string of code was defined once, given a two-letter name, and used later by giving a one-line macro command; the specifics which varied from problem to problem are called parameters.

The use of macros reduced the effort required to present many different, but basically similar problems. The macro capability of the source language had two distinct advantages over code written command by command. The first was ease and speed of coding; the call of one macro was obviously easier than writing the comparable string of code. The second advantage was increased accuracy. Not only were coding errors sharply curtailed, but defective macros or changes in the lesson coding could be corrected by modifying the original macro; in general, the code stayed as it was. The more standard the problem format, the more valuable the macro capability became. Apart from a few nonstandard instructional audio messages and display items, approximately 90 to 95 per cent of all the reading curriculum was programmed using roughly 110 basic macros.

In the 1967-68 school year, a major effort was made to move the students through the lessons at a faster rate. The lesson code was revised to speed up two areas that proved hindrances to student progress: restart pointshad been placed too far apart, and audio responses had been too slow. Revisions of the lesson code progressed in two stages. For Level II, interim macros were written to adjust the distance between restart points and to minimize audio delay by pre-positioning for a CA audio while the student responded. A second and final set of macros was written for use in Level III and beyond. Revisions were incorporated in the interim macros, and also replaced the CA audio with a smiling face on the CRT. The word "no" in the WA audio was also replaced by a crying face. The use of smiling and crying faces positioned the audio to the next instructional message, while the student received visual reinforcement or feedback.

The final step in translating the lesson material to a form usable in the computer was the lesson assembly process. A series of machine-language programs read in the coded lessons, expanded the macros, translated the audio code to actual tape addresses from the audio assembly table, and finally read out the assembled lesson translated into binary code onto a disk.

The final editing step was the debugging process that was carried out at the student terminals by working through all the correct and incorrect responses for each lesson. Errors left uncorrected from any stage in the production processes were detected as they might be seen by a student. Corrections were made, and the lesson checked again in a similar manner. This iterative debugging process proved vital in eliminating human error inherent in the complex process of lesson production.

Chapter 4

Findings and Analysis

4.1. Student Progress in Mathematics

A primary objective of CAI is to accommodate individual differences by providing a variety of paths through the curriculum, such as allowing the faster student to proceed to new problems as soon as he exhibits mastery of the old, while giving the slower learner remedial material if necessary. Each child worked independently of the others. An examination of the progress of the students and their spread over the lesson material as shown in the following sections gives a partial evaluation of the effectiveness of the Stanford-Brentwood program of computer-assisted instruction.

Mathematics progress, November-December, 1966. On November 7, a regular schedule was established for children in the terminal room. Groups continued to be divided into two 10-minute periods, with seven proctors each assigned to listen with one child. By November 9, most children started their lessons without help from a proctor, and by November 14, most students were working in Books 2 and 3. In the month of November, the children's work on-line was interrupted by three major systems breakdowns; i.e., one group on November 7, all groups on November 10, and two groups on November 30 were unable to work on the machines. With the exception of the above groups, children worked on the machines for a total of 23 days up to December 16. The progress of the children in the programmed lessons is shown in Table 3.

Mathematics progress, January-March, 1967. By January 1, most children were doing lessons on numeral recognition, counting and N-notation. A few children were introduced to addition (Book 7), and a few were still finishing the lessons on set union. By the end of March, most children finished the introduction to addition, lessons on sequences, the introduction to number line, sums through nine, and lessons on open and closed figures, concave and convex figures, and linear measure. Problems were begun which required the student to supply the missing addends. A few children finished the missing addend problems, as well as some lessons on number words. The progress of the children through the programmed curriculum is shown in Table 4.

Mathematics progress, April-June, 1967. During the period from April 1 to June 24, most of the children were doing programmed lessons on addition and subtraction to 10, and some progressed through sums greater than 10. Other topics included counting dimes and pennies as an introduction to the numbers from 10 to 20, and as readiness for the study of place value; number words zero through ten; one-half of an object; measuring isolated line segments and sides of polygons; recognition of similar figures in various sizes and positions; and concave figures. Table 5 shows the number of children working in each book during a given week. These children who had advanced farthest by the end of the year had done few remedial lessons during the entire year, while those students who completed the fewest number of books spent a great deal of time on remedial work.

TABLE 3

Mathematics Progress, November-December, 1966

	Oct. 24 -Oct. 29	Oct. 31 -Nov. 4	Nov. 7 -Nov. 11	Nov. 14* -Nov. 18	Nov. 21 -Nov. 25	Nov. 28 -Dec. 2	Dec. 5 -Dec. 9	Dec. 12 -Dec. 16
Book 1	49	17	4	4				
Book 2A		2	39	39	8		1**	
Book 2B		6	6	6	20	4		
Book 3A					21	20	7	1
Book 3B						17	14	4
Book 4						8	18	11
Book 5							8	23
Book 6A							2	6
Book 6B								4
Book 6C								1

*During the week of Brentwood Parent Conferences (November 14-18) no children came to the laboratory for mathematics lessons.

**This child entered school on December 6.

TABLE 4

Student Progress in Programmed Mathematics Curriculum

	Jan 3-6	Jan 9-13	Jan 16-20[1]	Jan 23-27	Jan 30-Feb 3	Feb 6-10	Feb 13-17	Mar 20-24	Feb 27-Mar 3	Mar 6-10	Mar 13-17	Mar 20-24[2]	Mar 27-31
Book 4	4												
Book 5	13	5	1										
Book 6A	17	6	5	5	1								
Book 6B	9	9	3	1	4	2							
Book 6C	1	12	9	6	5	5	4	4	4	4	4	4	4
Book 7A	4	11	15	14	3	5	5	4	4	4	4	4	4
Book 7B	2	2	10	9	14	5	5	3	3	3	3	3	3
Book 8		2	3	10	12	11	4	5	1	1	1	1	1
Book 9A		3		1	4	9	11	2	4	1			
Book 10			4	2	5	6	9	11	3	2			
Book 9B				2	2	7	4	9	5	2	2	2	
Book 14A							8	12	20	22	12	12	10
Book 14B									6	2	10	10	2
Book 15A										6	6	6	12
Book 15B										3	7	7	7
Book 16A											1	1	7

1. One student left the school; one new student was enrolled (starting in Book 6).

2. Spring vacation, March 20 - March 24.

TABLE 5

Number of Children in each Book of Programmed Mathematics Curriculum Shown by Weeks

Book	April 3-7	April 10-14	April 17-21	April 24-28	May 1-5	May 8-12	May 15-19	May 22-26	May 29-June 2	June 5-9	June 9-1
6C	3	1	1								
7A	4	1									
7B	2	2	2	1	1						
8	1	2	2	2*		1	1	1	1		
9A	2	3	2	3	1						
10	1	1	3	5		1				1	1
9B		1		1	4	1					
14A		1	2	2	4	1	1				
14B	1				1	6	3				
15A	6	1			1						
15B	4		1			1	1				
16	14	7	1		2		5	5	2	1	
17A	6	6	8	7	1	3	1	5	4	4	4
17B	6	20	8	5	2		2	1	3	3	3
18A		4	8	11	6**	2	2	2	3	2	1
18C			12	7	5	5		5	1	1	2
18B				8	14	6	7	3	5	2	2
19A					4	8	4	4	3	3	3
19B					5	8	4		2	3	1
20A					1	4	6	13	7	3	4
20B					1	5	9	6	5	7	8
21A						1	2	1	1	1	1
21B							5	5	5	1	1
22A								2	6	6	
22B									4	4	9
22C										2	1
23A										1	2
23B										4	1
24A										1	4
24B										2	2
25A											
25B											2

* Two children enrolled, started in Book 8.

** One child enrolled, started in Book 18A.

Mathematics progress, July-September, 1967. On September 20, the students began the programmed lessons. After eight days of CAI instruction, the fastest child had completed 5-1/2 books (62 lessons), while the slowest child had completed 2 books (25 lessons).

Mathematics progress, October-December, 1967. As of September 29, the last day of the preceding quarter, the spread of the children was from Book 1 through Book 5 after eight days on-line. At the end of the quarter, the spread was from Book 6 through Book 19. The progress of the students through the curriculum was one indicator of student achievement; another was the proportion of problems to which students responded correctly. Table 6 shows the number of children whose achievement for a given week fell within the indicated range of percentage correct.

Mathematics progress, January-March, 1968. By the end of March, 73 children worked on-line on the mathematics curriculum. Where the spread of the children at the end of the preceding quarter was from Book 6 through Book 19, at the end of this quarter the spread was from Book 11 through Book 35. Table 7 showns the number of children whose achievement for the week fell within the indicated range of percentage correct.

4.2. Data Analysis in Mathematics

Testing program. The Individual Stanford Binet I.Q. (short form) was given to 100 Brentwood first graders in the fall of 1966 and the Stanford Achievement Test, Primary I Battery, Form W was administered the following spring.

Half of these students, the control group, did not participate in the computer-assisted mathematics program; the other half of the students, the experimental group, participated in the mathematics program for the 1966-67 school year.

Table 8 shows average SAT scores, in terms of grade equivalence, and the average I.Q. for the control and experimental groups. Data are also presented for each of these groups which were further divided into low and average groups by I.Q. There was no significant difference in I.Q. between the experimental and control students for any of the three possible comparisons. The *t* tests on the SAT scores were significant only for the low I.Q. group where the subjects in the experimental group performed better than the subjects in the control group.

Within the average I.Q. group, the experimental girls performed significantly better on the SAT than the control girls; within the low I.Q. group, the experimental boys performed significantly better than the control boys. Also, within the experimental groups, there were no significant differences between the performance of girls and boys. Therefore, the groups that seemed to benefit most from computer-assisted instruction were boys with a low-measured I.Q. and girls with an average-measured I.Q.

TABLE 6

Distribution of Children in Mathematics Curriculum According to Percentage Correct for the Week

Week of:	60% and below	61-65%	66-70%	71-75%	76-80%	81-85%	86-90%	91-95%	96-100 %
Sept 20-22	0	0	0	1	4	8	18	19	19
Sept 25-29	0	1	1	0	4	11	28	21	5
Oct 2-6	0	1	0	4	12	17	21	17	0
Oct 9-13	1	5	3	8	13	16	19	7	0
Oct 16-20	0	0	5	4	16	20	19	7	1
Oct 23-27	2	1	2	10	17	13	18	13	0
Oct 30-Nov 3	2	2	4	8	9	19	16	13	2
Nov 6-10	3	1	2	7	13	15	15	17	2
*Nov 13-17	1	2	1	6	6	5	5	5	0
Nov 20-22	3	2	2	4	11	17	17	13	3
**Nov 27-Dec 1	1	0	0	10	9	14	22	16	1
Dec 4-8	0	1	1	7	12	13	19	17	3
Dec 11-14	1	3	2	14	7	15	14	19	1

*Only children in Groups II and III received programmed material.

**Data lost for Nov. 30.

TABLE 7

Distribution of Children in Mathematics Curriculum According to Percentage Correct for the Week

Week of:	60 and below	61-65	66-70	71-75	76-80	81-85	86-90	91-95	96-100
Jan 2-5	1	1		6	18	13	14	17	
Jan 8-12	5	1	3	8	5	16	16	12	5
Jan 15-16, 18-19	9	1	5	1	7	9	19	7	7
Jan 22-26	3	2	3	3	11	16	20	12	2
Jan 29-Feb 2		3	4	2	13	15	19	12	5
Feb 5-9	2	5	4	4	12	12	21	11	3
Feb 13-16	2	1	2	6	9	13	18	17	5
Feb 19-21, 23	1		3	11	6	16	22	13	3
Feb 26-Mar 1	2	2		6	7	18	17	16	6
Mar. 4-8	4	1	4	4	6	12	20	19	5
Mar 11-15			2	4	8	17	25	15	1
Mar 18-22		2		4	5	23	25	12	3
Mar 25-29		2	1	1	4	20	24	16	3

TABLE 8

Testing Results for First-grade Mathematics Curriculum
1966-67

	I.Q. (Fall)		SAT (Spring)	
Group	Experimental	Control	Experimental	Control
Total	91.4	92.9	1.53	1.46
Average I.Q.	99.3	100.3	1.72	1.67
Low I.Q.	82.8	81.9	1.32	1.15

Analysis of problems. The data obtained from the 1966-67 Brentwood mathematics projects were analyzed by using a regression model. The curriculum was divided into six separate categories, and each category was analyzed as a unit. These categories corresponded to arithmetical concepts of sets, geometry, counting, addition, and subtraction. Owing to nonhomogeneity of problem types, the set problems were subdivided into two parts; sets A corresponding to problems in the first half of the curriculum, and sets B corresponding to problems in the second half of the curriculum. For a problem to be included in the analysis, at least 36 students had to attempt it. For latency analysis, it was also required that there be no audio message prior to first response. All problems that met any of the following three criteria were not included in the analysis. First, in certain lessons the range of difficulty (as measured by proportion correct) was not sufficiently large to make a regression analysis meaningful. Second, because of machine error, there were several lessons for which response data were not reported. Finally, there were 33 lessons that contained problems which dealt with miscellaneous, heterogeneous topics and were, therefore, not amenable to a structural analysis.

The two dependent variables considered were proportion correct and success latency. A set of independent variables was defined for each category and reflected the structural characteristics of the problems studied. In all cases where the definition of a variable did not apply, the value of that variable was zero. The independent variables were:

Sets:

X_{s1} - number of distinguishable symbols on the CRT;

X_{s2} - number of times the order of members of the stimulus set had to be permuted, two at a time, to have the same order as members of the correct choice set;

X_{s3} - one if there exists at least one incorrect choice set with the same cardinality as the correct choice set;

X_{s4} - one if the correct choice is the second or third alternative;

X_{s5} - number of response alternatives;

X_{s6} - one if the empty set occurs in the problem;

X_{s7} - two if the empty set occurs in the problem, is the correct choice, and is part of the stimulus; one if the empty set occurs in the problem, and the empty set is the correct choice and is not part of the stimulus;

X_{s8} - number of times a member of the correct choice set occurs as a member of the incorrect choice sets;

X_{s9} - one if a blank occurs to the right of a union sign and to the left of the equal sign;

X_{s10} - one if the choices consist of unions of sets.

Geometry:

X_{g1} - if the problem involves the identification of squares or rectangles, X_{g1} is the magnitude of the following sum: two if an incorrect choice has four equal sides, or one if any incorrect choice has four sides, plus three if an incorrect choice has four right angles, or two if an incorrect choice has two right angles, or one if an incorrect choice has one right angle, plus one if an incorrect choice is oriented such that it is supported on its base;

X_{g2} - if the problem involves the identification of triangles, one if there is an incorrect choice with the shape of a triangle;

X_{g3} - one if the correct choice is oriented such that it is supported by one of its sides;

X_{g4} - one if a problem has three choices;

X_{g5} - one if the first choice is the correct choice;

X_{g6} - one if the second choice is the correct choice;

X_{g7} - one if the third choice is the correct choice;

X_{g8} - one if there is an incorrect choice with a non-zero value of X_{g1} or X_{g2} immediately before or after the correct choice;

X_{g9} - one if the problem contains a different number of choices from the immediately preceding problem.

Counting:

X_{c1} - number of distinguishable symbols on the CRT excluding digits and/or names of digits;

X_{c2} - the correct response;

X_{c3} - the value of the smallest incorrect response alternative divided by the difference in value between the smallest incorrect response alternative and the correct response;

X_{c4} - the number of digits displayed;

X_{c5} - one if the problem required a "yes" or "no" response;

X_{c6} - one for each problem in the lesson which first presented N-notation;

X_{c7} - one if the problem required a typed response;

X_{c8} - one for each problem in the first lesson to require counting objects on the scope and choosing a word response or the first lesson to require counting the number of sides of a polygon and choosing a digit response;

X_{c9} - one if the problem was classified as an explanation problem.

Addition:

X_{+1} - number of symbols on the CRT;
X_{+2} - the largest addend;
X_{+3} - the smallest addend;
X_{+4} - the sum;
X_{+5} - the value of the smallest incorrect response alternative divided by the difference in value between the smallest incorrect response alternative and the correct choice;
X_{+6} - two if the blank is to the left of the equal sign and to the left of the plus sign, or one if the blank is to the left of the equal sign and to the right of the plus sign;
X_{+7} - one if the problem required a typed response.

Subtraction:

X_{-1} - the dimuend;
X_{-2} - the subtrahend;
X_{-3} - the difference;
X_{-4} - one if the counting marks were displayed, but the number equal to the subtrahend was not crossed out, or no counting marks were displayed;
X_{-5} - one if no counting marks were displayed;
X_{-6} - the magnitude of the inverse of the number of times a specific problem had been given up to that point;
X_{-7} - one if a problem had a vertical format.

Tables 9 and 10 summarize the results of the regression analyses. The multiple correlation coefficients show that the fit for success latency was better than the fit for proportion correct. In each of the categories, some of the variables tried were found to contribute significantly to the prediction of the dependent variable, others did not. Significance was determined by means of a t-test on the regression coefficients. It was found the variables that were significant in predicting proportion correct were not necessarily the same ones which were significant in predicting success latency.

This analysis was a first attempt to isolate some of the structural variables which accounted for the difficulty and the latency to success of first-grade mathematics problems, not taking into account the audio messages given with these items. Also, no attempt was made to systematically analyze the types of errors made on the items. Several important factors were found which definitely affected group performance on the items, although certainly not all such factors were discovered. There were indications that suggested the context in which the items were presented was also a significant factor. Finally, areas were found in which our understanding of the structural factors involved was particularly weak, notably, in geometry.

TABLE 9

Regression Coefficients for Brentwood Mathematics Group Probability Analysis

Concept	Number of problems	Constant	$X_{.1}$	$X_{.2}$	$X_{.3}$	$X_{.4}$	$X_{.5}$	$X_{.6}$	$X_{.7}$	$X_{.8}$	$X_{.9}$	$X_{.10}$	R	R^2
Sets A	94	-3.01	.01*	.13*	.05*	.18*		.16*	.62	.33			.61	.37
Sets B	65	-2.17	.05	.10*		-.19	.04*					-.99	.65	.42
Geometry	48	-5.05	.37	1.04	.05*	.33*	.64*	.91*	.41*	.99*	1.81		.68	.46
Counting	270	-3.02	.11	.04	.01*	.10	.04*	.64*	.32*	.86	.01*		.50	.25
Addition	161	-1.18	-.01*	.11*	.16*	-.06*	.22*	.84	-.63				.51	.26
Subtraction	125	-1.66	-.30*	.26*	.27*	-.58	1.62*	-.97	-.19				.72	.52

*t score for regression coefficient < 2.00

TABLE 10

Regression Coefficients for Brentwood Mathematics Group Latency Analysis

Concept	Number of problems	Constant	$X_{.1}$	$X_{.2}$	$X_{.3}$	$X_{.4}$	$X_{.5}$	$X_{.6}$	$X_{.7}$	$X_{.8}$	$X_{.9}$	R	R^2
Sets A	44	1.48	.15	.48	.50*					.44		.87	.75
Sets B	40	3.31	.17	.28*	-.61*		.43	-.49*		-.01*		.76	.58
Geometry	24	1.21	.17*	.75*	-.11*	.22*	1.00*				1.74	.67	.45
Counting	110	3.16	.38	.15	.17*	.21		-.57				.81	.65
Addition	99	5.62	.07	.11*	.07*	.43	.10*	1.18	-.99			.70	.48
Subtraction	64	5.28	-.63*	.93	.94	-1.51	3.26	-2.58	-.80*			.82	.68

*t score for regression coefficient < 2.00

Individual models. The analysis of data for individual students in the first-grade mathematics program was completed. The purpose of the analysis was to determine whether certain factors could predict a student's performance on a given set of lessons. Unlike the factors based on problem structure used in the "structural analysis," the factors used in this analysis were measures of prior performance of the individual. Two measures of performance were involved: the proportion of problems which the student answered correctly on the first response, and the student's average latency to the first response on correct problems.

Standard regression models were used to obtain the predictions. Two theories were involved in choosing the specific models. One theory was that the best indicator of a student's future performance is his most recent past performance. This line of reasoning led to the "temporal" models in which the prediction of an individual's performance in a given block of lessons was based on his performance in the immediately preceding blocks of lessons. The other theory was that performance depends on the degree of understanding of the information (terms, symbols, concepts, etc.) needed to complete the new task. This idea led to the "conceptual" models in which the prediction of an individual's performance on a given set of lessons was based on his performance on previous lessons which presented the same concept.

Since the individual difference in performance at two points in the curriculum depends upon both the "normal" variability of the individual and the particular curriculum points chosen, the parameters for the various models were estimated in two ways. The first method, estimation of group parameters, accounted for differences in performance for the curriculum points examined. In this case, one set of parameters was estimated for each set of lessonswith the estimation based on the performance of all students on the preceding set of lessons appropriate to the model under consideration. Thus, to predict an individual's performance, a different set of parameters was used for each block of lessons; for a given block, the same set of parameters was used for all students.

The second method, estimation of individual parameters, accounted for changes in performance specific to an individual. In this case, one set of parameters was estimated for each student based on his performance on all lessons. Thus, to predict an individual's performance, a set of parameters was used which was unique to that student but was the same for all blocks of lessons; for a given block, a different set of parameters was used for each student. The individual estimation technique was modified for some models to include, to some extent, differences in curriculum. Individual parameters for these models were estimated more than once, each based on a different segment of the curriculum (e.g., each set of four lessons). Thus, the set of parameters used to predict an individual's performance was unique to the individual and to the segment of the curriculum under consideration.

Comparisons of the various models were based on a total X^2 value when proportion correct was the dependent variable and on the S^2 value when latency was the dependent variable (Suppes, Hyman, and Jerman, 1967).[1] For proportion correct, the conceptual models predicted individual performance better than the temporal models with both the group and the individual parameter estimation techniques. Thus, a student's performance on a given topic is more dependent upon his past performance on that topic than upon his more recent performance on a different topic. For latency data, there were no differences between the temporal and conceptual models.

Again, considering data in terms of proportion correct for both the temporal and conceptual models, group parameters gave better predictions than the individual parameters. For the temporal models, the modified individual estimation technique yielded predictions which were better than the individual parameters based on all the student data, but were not as accurate as the group parameter predictions. For the latency data, all models based on group parameters were better than the models estimated by individual parameters.

4.3. Student Progress in Reading

Reading progress, November-December, 1966. The reading curriculum was organized around a main-line or core of problems and exercises for which each student had to exhibit some degree of competency. The lessons averaged approximately 100 to 125 main-line problems each, excluding remedial loops, corrections, optimization routines, and accelerated branchings. At the beginning of Christmas vacation, the maximum number of sessions for any child on the system was 24, disregarding illnesses, school vacations, and terminal and system failures. This amounted to eight hours of instruction at the response terminal. The spread between the slowest and fastest student at the beginning of the Christmas vacation was 600 main-line problems after eight hours of instruction. Table 11 indicates the distribution of the students.

Reading progress, January-March, 1967. The range of distribution of students over the lessons continued to increase. The range was eight lessons at the beginning of January and 25 lessons at the end of March. The range is not easy to interpret since it reflects demographic movement in the student population. Four students transferred out and four transferred in. A range of the distribution given in terms of the median and inter-decile range, is shown in Figure 3. The latter increased from three lessons at the beginning, to 14 lessons at the end of the period. (see p. 21)

Figure 4 indicates a rate-of-progress curve, plotted for the fastest and slowest students in the original population. The position of the student in the lesson material was plotted against the cumulative number

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[1] Suppes, P., Hyman, L., & Jerman, M. Linear structural models for response and latency performance in arithmetic on computer-controlled terminals. In J. P. Hill (Ed.), Minnesota Symposia on Child Psychology. Minneapolis: Univ. of Minn. Press, 1967. Pp. 160-200.

TABLE 11

Student Distribution in Brentwood Reading Curriculum
November to December, 1966

		November					December		
		2	9	16	23	30	7	14 -	-16
Introductory Lessons	A	51							
	B		33	7					
	C		18	12	3	1			
Level 1	1			31	37	21	6	1	1
	2				10	25	34	26	19
	3					3	6	15	13
	4						3	4	13
	5						1	3	0
	6							1	3
	7								1
	8								
	9								
	10								
	11								
	12								
	13								

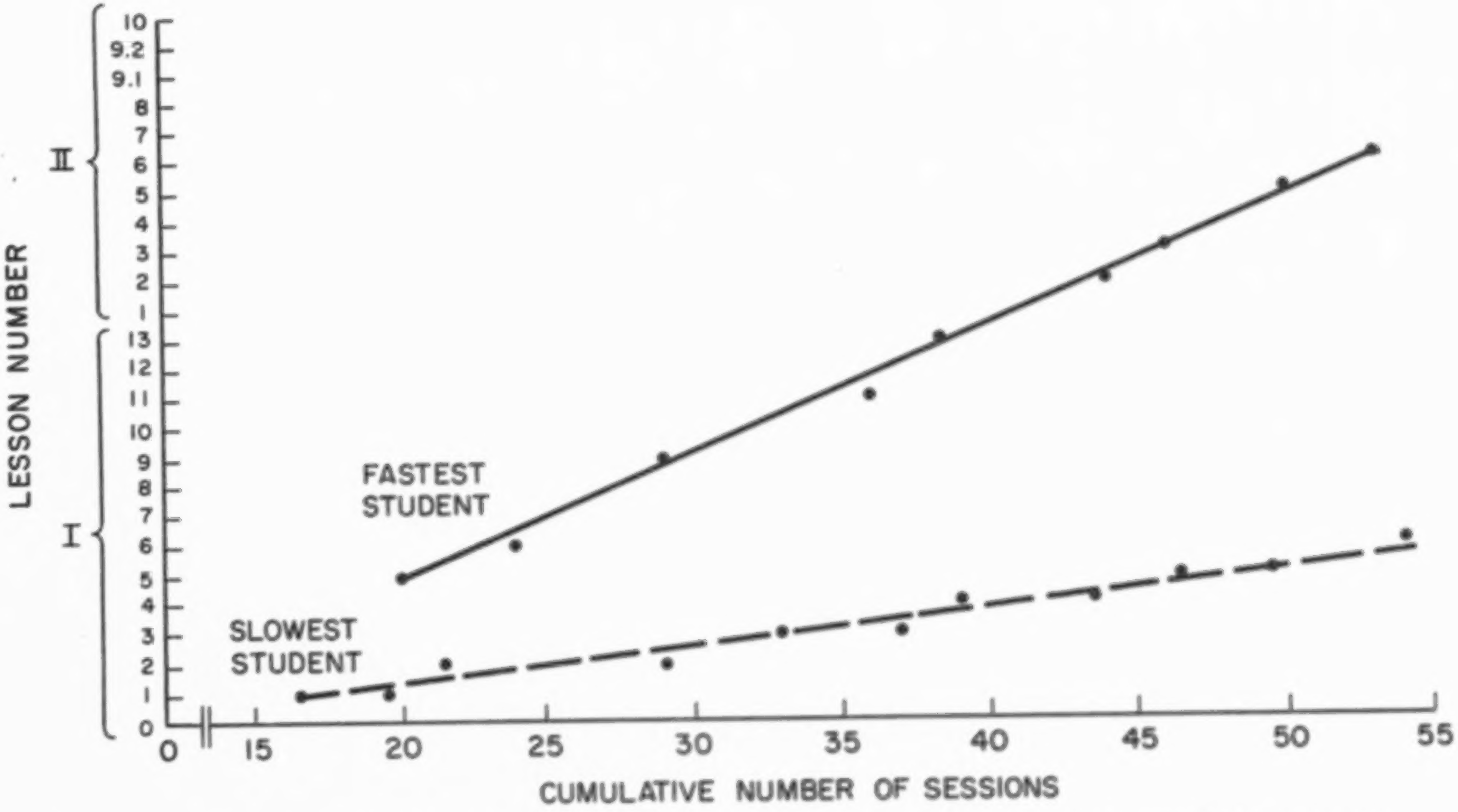

Fig. 4. Position in Reading Curriculum by Week plotted Against Cumulative Number of Sessions on System for Fastest and Slowest Student in Original Student Population

of sessions the student had been at the terminal. The curves indicated that, at least for this period, the rate of progress for the two extreme subjects was essentially linear; the curves differed only in slope.

Reading progress, April-June, 1967. Thirteen remedial-reading students from two second-grade classrooms were brought on the system on a daily basis during the period. They adapted quickly to the environment and their progress was satisfactory. The classroom teachers reported an increase in interest and application to classroom reading instruction by the students involved in the program.

A graph of the cumulative rate of progress for the remedial second-grade students after eight weeks of instruction is compared in Figure 5 with that of the regular first-grade students at the end of their first eight weeks of instruction. The range of the second-grade remedial students was from 58 to 131 main-line problems per hour with the median at 104. It is interesting to note that the bottom of the second-grade remedial distribution falls just under the median of the first-grade distribution.

The year ended with a difference between the fastest and slowest student of 4,125 problems completed. The inter-quartile range was 1,375 problems, and the median student completed 2,625 main-line problems. The range in rate of progress was between 35 problems per hour for the slowest student to 170 main-line problems per hour for the fastest student. The inter-quartile range was 45 to 110 with the median at 75 problems per hour.

Reading progress, July-September, 1967. On September 20, the children began work on Days 1 and 2 with the introductory lessons. On September 25, they began Day 3, which consisted of the revised letter-teaching lessons. On September 29, after the first week of instruction, the students were distributed as follows:

Lesson	Number of Students
Day 3	42
I-01	24
I-02	10
I-03	3
	79

Reading progress, October-December, 1967. On December 15, 76 first-grade students continued to receive computer-assisted instruction in reading. The method of presenting the curriculum was modified, thereby substantially increasing the students' rate of progress through the curriculum. By the third week, this year's most advanced student was three lessons ahead of last year's students; by the tenth week he had covered twice as many lessons.

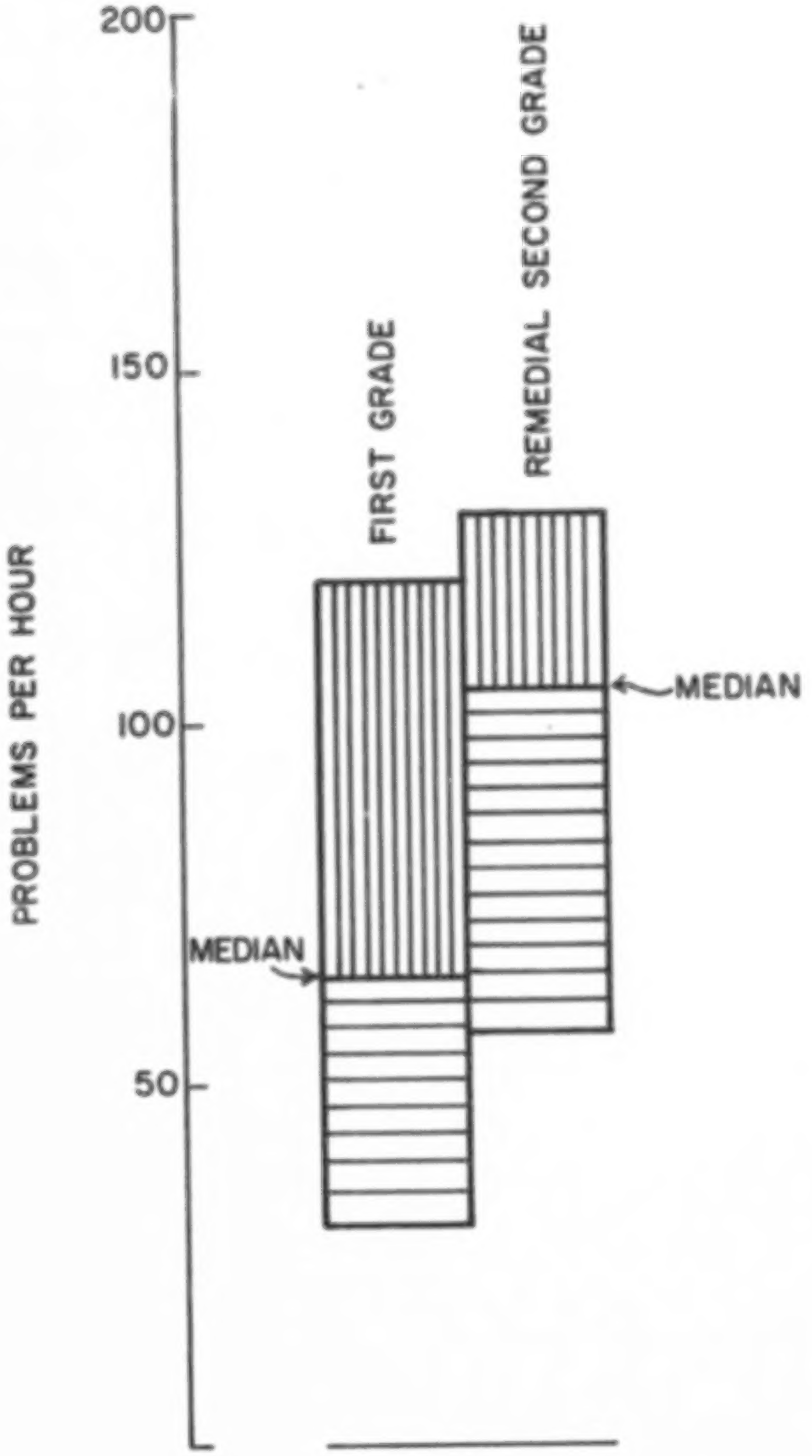

Fig. 5. Comparison of the Distribution of Rate of Progress of First-grade and Remedial Second-grade Students after Eight Weeks of CAI Reading Instruction

Reading progress, January-March, 1968. On March 29, 80 first graders worked on the curriculum in addition to 7 remedial fourth graders who began work on March 13. By the end of the thirteenth week, this year's fastest student had completed 21 lessons more than last year's fastest student; by the end of the twenty-fifth week, he had completed 23 lessons more.

Summary of student progress in mathematics and reading. The increasing spread of the students over both the mathematics and reading curricula indicated that some individual differences in the learning characteristics of the student populations were accommodated in the curriculum. The faster students quickly proceeded through material which they mastered, and the slower students took a different path, receiving remedial material. Since no two students followed an identical path, computer-assisted instruction did permit students to advance at their own rates of progress.

4.4. Data Analysis in Reading

As each student response was input into the system, it was recorded in a concise form that identified the student, the particular problem he was working on, the response made, and the response time. Thus, the complete history available for each student was used in making real-time decisions about the instructional sequence, and for later evaluations and analyses.

Analysis of response data (1966-67). Preliminary 1966-67 data were run for (a) analyses of running averages kept on four curriculum blocks; (b) effects of word-usage frequency on the probability of correct responses in the matrix criterion test; and (c) analyses of learning in the matrix block.

The running averages were derived from the proportion of correct answers to the total number of responses requested in the main-line lesson blocks (letter learning, word-list learning, matrix comprehension). The proportions for each lesson were combined with the past lesson data by weighting the past to present results on a four-to-one ratio.

The running averages for four lessons were selected, and intercorrelations between these running averages were computed. The results are shown in Table 12. The lessons selected were Level I, Lessons 5 and 8, and Level II, Lessons 1 and 7. It should be noted that some of the slower students did not progress beyond Lesson I-8, so the number and characteristics of the students differed between Lesson I-5 and Lesson II-7.

Since the correlation coefficient was a measure of how well responses to one variable predicted responses to another variable, it was interesting to observe how well the responses in a specific learning block predicted how the student responded in other blocks. The circled correlations in Table 12 are estimates of how well the responses to the block represented in the left-hand column predicted responses in the same blocks in other lessons. For example, the letter block of Lesson I-5 predicted very

TABLE 12

Intercorrelations Between Running Averages on Four Blocks of the Brentwood Reading Curriculum

Lesson	I-5				I-8				II-1				II-7			
Block	L	W	M	C	L	W	M	C	L	W	M	C	L	W	M	C
I-5 Letter		.48	.37	.33	.95	.42	.47	.45	.89	.34	.53	.40	.69	.34	.29	.37
I-5 Word			.20	.34	.47	.84	.40	.52	.45	.66	.49	[illegible]	.42	.58	.56	.53
I-5 Matrix				.14	.31	.24	.81	.16	.45	.44	.68	.28	.48	.47	.43	.37
I-5 Compre.					.31	.34	.32	.76	.42	.34	.40	.88	.33	.45	.51	.63
I-8 Letter						.43	.36	.38	.95	.37	.39	.33	.73	.31	.07	.15
I-8 Word							[illegible]	.61	.42	.80	.44	.43	.45	.70	.55	.47
I-8 Matrix								.48	.52	.60	.81	.46	.46	.70	.62	.59
I-8 Compre.									.44	.55	.55	.86	.43	.63	.64	.71
II-1 Letter										.36	.40	.44	.80	.30	.10	.28
II-1 Word											.57	.35	.46	.83	.63	.59
II-1 Matrix												.55	.41	.74	.86	.72
II-1 Compre.													.30	.62	.65	.83
II-7 Letter														.43	.37	.28
II-7 Word															.77	.62
II-7 Matrix																.68
II-7 Compre.																

accurately the responses in the letter block of Lesson I-8 with a correlation coefficient of .95. However, as the lessons progressed, the correlation decreased. This decrease would suggest that the most recent information was the most valuable predictor. This same pattern seemed to be maintained in all of the blocks, with the exception of the comprehension block in Lesson I-5, which predicted the results of Lesson II-1 better than it did those of Lesson I-8.

The correlations within the triangles were the predictions from responses of each block within a lesson to responses from all other blocks within the lesson. As an example, the running average for the word block in Lesson I-5 did not predict very accurately the running average of the matrix block (correlation of .20). In Lesson I-8, however, this correlation increased to .45 and continued to increase as the lessons progressed. The reason for this increase is being investigated.

The second analysis was the effect of word-usage frequency on the probability of correct responses in the matrix criterion test. Analysis was based on data from the first-response data tape, which contained initial student responses to problems when first encountered. The data was sorted by lesson and, within each lesson, by student.

The proportion of correct responses each student made for each group of words was used as the measure in the analysis. Figure 6 indicates the mean proportion of correct responses on the matrix criterion test for the four-word groups and for each I.Q. group.

A two-way analysis of variance of these data showed there was a significant difference between both the I.Q. groups and the responses to the different word groups. There was no significant interaction, however, between the I.Q. groups and word groups, which suggested that the patterns of response to the criterion tests were the same for each I.Q. group.

The analysis, which involved all the new words presented in the first eight lessons, indicated that there was a significant difference in the proportion of correct responses on the matrix criterion test for the students grouped by I.Q., and for different word-frequency groups among all the students.

It was hypothesized that ignorance of the matrix concept was responsible for the significant drop in correct responses for the letter strings (nonsense items of zero frequency). In order to test the above hypothesis, a second analysis was made using the new words presented in Lessons I-9 through I-13. Assuming that the children had correctly learned the matrix concept by these later lessons, one would expect that frequency of word usage would no longer be a significant predictor of their performance.

Figure 7 is a graph of the mean responses for the words in the first eight lessons and the words in Lessons I-9 through I-13. Table 13 shows the mean and standard deviation for lists of each frequency. The t-tests between word lists showed that the high, low, and letter-string lists were

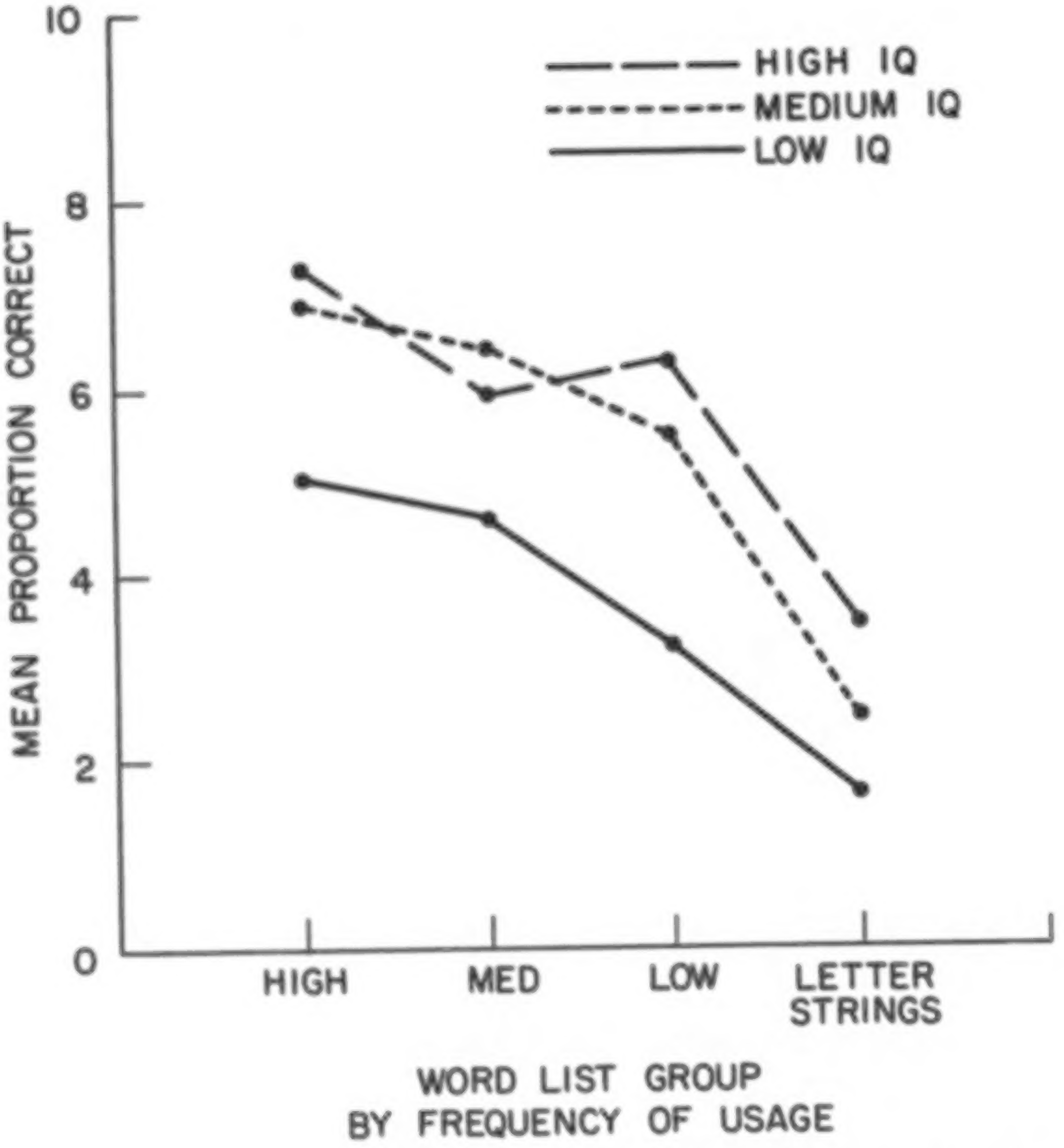

Fig. 6. Mean Proportion Correct of Word List for Three I.Q. Groups, Reading Curriculum

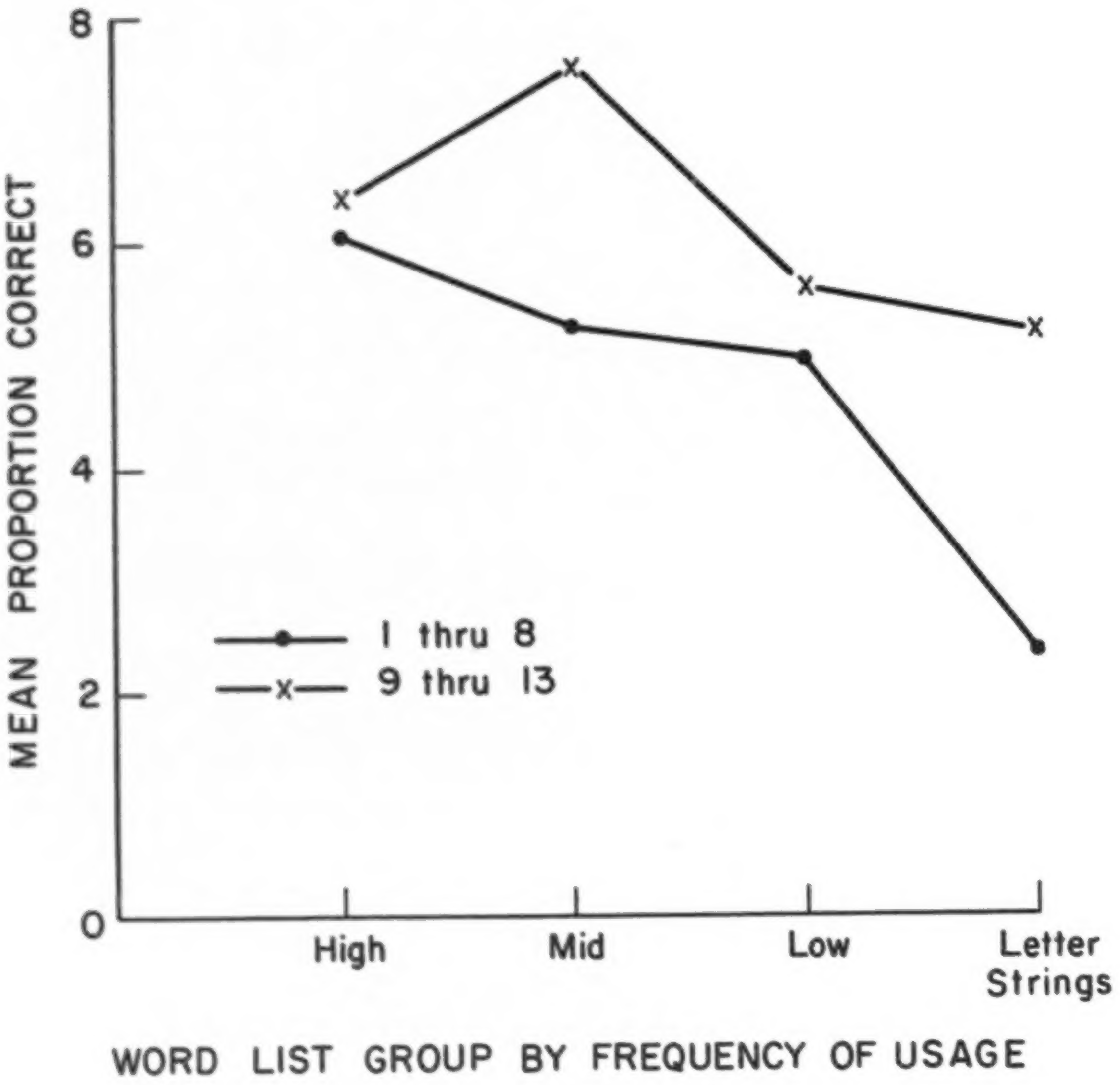

Fig. 7. Word-List Group by Frequency of Usage, Reading Curriculum

TABLE 13

Mean and Standard Deviation for Reading Curriculum Lists for Each Frequency

	Mean	Standard Deviation
List I		
High	0.63	0.30
Mid	0.55	0.30
Low	0.52	0.31
L.S.	0.26	0.29
List II		
High	0.64	0.23
Mid	0.72	0.24
Low	0.58	0.28
L.S.	0.54	0.28

not significantly different at $p = .01$. The middle-frequency word group, however, was significantly higher than both the letter-string and the low-frequency word groups.

The shift of the highest proportion of correct answers from the high-frequency list to the middle-frequency list suggested, along with the lack of significant differences between the other three word lists, that word frequency was not a significant factor in predicting the proportion of correct responses for students on the matrix criterion test.

The third preliminary analysis concerned learning in the matrix block. Matrix construction was a key learning activity present in each lesson. Certain regular, highly productive rhyming and alliterative word patterns were taught. Rhyming patterns were presented in the columns of a sounding matrix. Alliteration patterns were presented in the rows of the matrix.

The matrix was constructed one cell at a time. In the course of an errorless trial, the student heard the word pronounced three times and was asked to identify and pronounce it twice. In the initial presentation, the multiple-choice items were designed to identify three possible classes of error: (a) a correctly identified initial unit, but an incorrect final unit; (b) a correctly identified final unit, but an incorrect initial unit; or (c) incorrectly identified initial and final units. There was a special remedial treatment appropriate for each class of error. After all words in the matrix were presented, and remedial and practice exposures were completed, a subset of the items was presented in a criterion test.

The first-exposure data obtained from this matrix block is summarized as follows. Only the words used in the criterion test were considered. For these, a student's performance on the initial presentation and on the criterion test was examined, and responses were classified by types of error. The data from all students completing a given lesson were then summarized in a table of joint probabilities, which was used to estimate theoretical parameters that represented a condensed description of the data for the matrix block on the lesson in question. The parameters estimated were: (a) proportion of words known on entry to the block; (b) proportion of words for which the initial unit only was known on entry; (c) proportion of words for which the final unit only was known on entry; (d) proportion of unknown initial units learned before the criterion test; (e) proportion of unknown final units learned before the criterion test; (f) probability of not making a response when a word was not known.

An analysis of performance on the matrix task is still incomplete, but some preliminary results are available. On the initial pass (Part A) the students were correct about 45 per cent of the time; however, when an error did occur, 21 per cent of the time it involved only the final unit, 53 per cent of the time only the initial unit, and 26 per cent of the time both initial and final units. The pattern of performances changed markedly on the first pass through the criterion test. Here the subject was correct about 65 per cent of the time; when an error occurred, 32 per cent of the time it involved only the final unit, 33 per cent of the time only the initial unit, and 35 per cent of the time both units. Thus, performance showed a significant improvement from Part A to the criterion test; equally important, initial errors were more than twice as frequent as final errors in Part A, but were virtually equal on the criterion test.

Weekly report (1966-67). A weekly report on student progress was given to the teachers. The report contained the individual student's name, lesson placement, number of proctor calls received for that student during the week, and a cumulative weighted index of the student's performance for each of the six major problem blocks (i.e., letter discrimination, word presentation, matrix construction, comprehension, compound words, polysyllabic words). Also included in the report were the cumulative number of sessions the student had on the machine, his number of absences during the week, and the total amount of time off the system that week.

Spread on main line. It was necessary for each student to master a central core of problems within the lesson material. A student branched around blocks of main-line problems by successfully passing certain screening tests. On the other hand, a student branched to appropriate remedial material if he had difficulty with these central problems; but in every case he returned to that set of main-line problems for which remedial material was introduced.

Each lesson contained an average of 125 main-line problems. The number of lessons completed by a student was used as an index of the number of main-line problems successfully completed. Figure 8 shows the number of main-line problems completed each week by the fastest, slowest, and median student. This information was derived by identifying the student who had completed the most lessons on the final student progress report for the week of June 14. The same report identified the median student and the slowest student. Only those students who had begun the program on November 15, 1966 were included. New students to the school and the remedial second-grade students were not considered in the derivation of Figure 8.

The year ended with a difference between the fastest and slowest student of 4,125 completed problems. The inter-quartile range was 1,375 problems, and the median student completed 2,625 main-line problems. There was, however, a rather wide variation in the amount of time spent on the system by the students. In order to take this variation into account, a rate-of-progress score was computed by dividing the number of problems completed at the end of the year by the number of sessions the student had on the system. The cumulative rate of progress for the highest, lowest, and median student is shown in Figure 9, and is expressed in terms of number of main-line problems completed per hour of instruction. The range in rate of progress was between 35 problems per hour for the slowest student to 170 main-line problems per hour for the fastest student. The inter-quartile range was 45 to 110 with the median at 75 problems per hour.

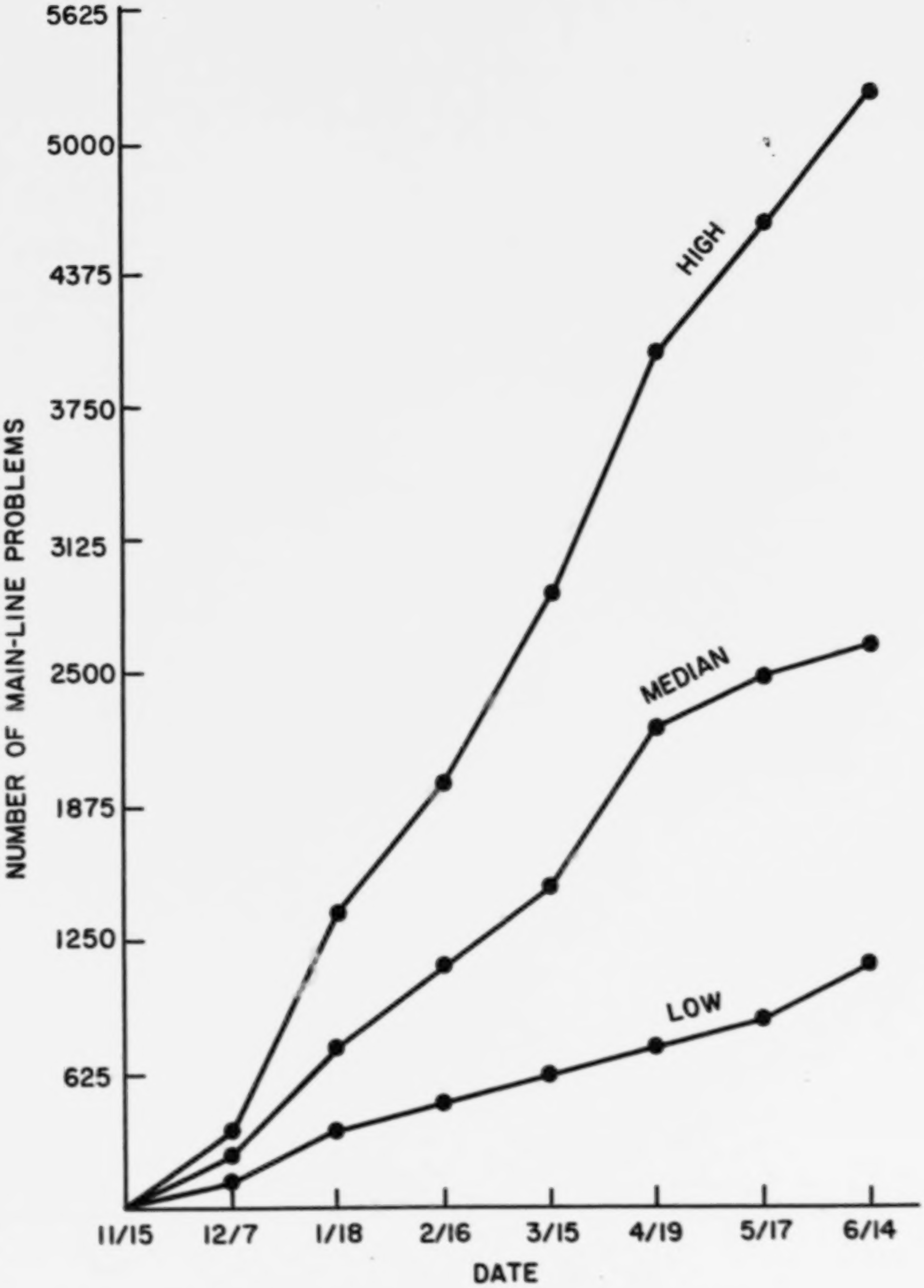

Fig. 8. Number of Main-line Reading Problems
Completed Each Week by Fastest, Slowest, and Median Students

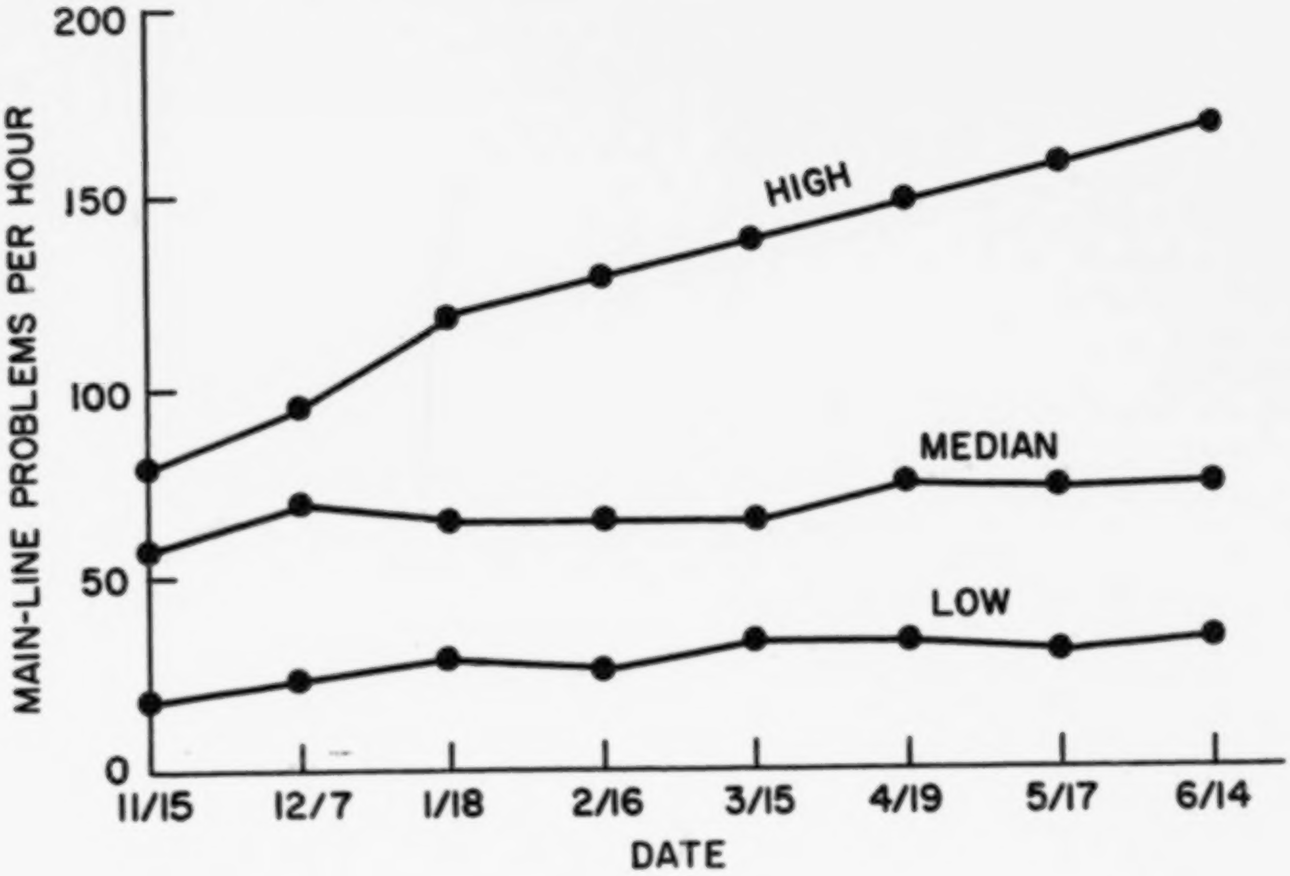

Fig. 9. Cumulative Rate of Progress of Fastest, Median, and Slowest Students in CAI Reading Program

From both the total number of main-line problems completed during the year and the rate of student progress, it is clear that the CAI reading curriculum accounted for individual differences on at least one dimension (i.e., the movement of the individual student through the lesson material). As shown in Figures 8 and 9, the differences are not to be confused with a variation in rate of response. The differences in the rate of response between students was very small--approximately four responses per minute. The differences in the total number of main-line problems completed and in the rate of progress are explained by variations in the amount of remedial material, the optimization routines, the number of corrections, and the number of accelerations for the different students.

Sex differences. Generally, girls surpass boys in the acquisition of reading skills and in reading performance, particularly in the primary grades (Gates, 1961;[1] Wyatt, 1966[2]). These differences might be attributed, at least in part, to the social organization of the classroom and to the value and reward structures of the predominantly female primary-grade teachers. It has also been argued that because of differences in developmental rates, first-grade girls are more adept in visual memorization than boys of the same age--a capability that would favor girls in the sight-word method of vocabulary acquisition commonly used in the current basal reading series. If these two arguments are true, then one would expect that placing students in an asocial environment, such as a CAI tutorial system, and presenting a linguistically oriented curriculum emphasizing analytic skills as opposed to rote memorization of words, would minimize the sex difference in reading performance. To test this notion, the rate-of-progress scores taken from the final teachers' reports were rank ordered and tested for significant sex effects using a Mann-Whitney U-Test. The null hypothesis in this and in the following tests was that the score for the boys and the scores for the girls had the same distribution. The test of sex effects yielded z of .05. Under the null hypothesis, the probability of z being greater than or equal to 0.35 was 0.36. Sex difference then is not an influential variable in the rate of progress in the Stanford CAI reading curriculum.

To test the notion that sex differences still might be an influential factor in accuracy of performance, the final performance index scores for each of the four standard problem blocks reported on the weekly teachers' reports were rank ordered and examined under the Mann-Whitney U-Test. The results were as follows:

Letter identification; $Pr(z \geq 0.33) = 0.37$.
Word list; $Pr(z \geq 1.83) = 0.03$.
Sounding matrix; $Pr(z \geq 1.41) = 0.08$.
Sentence comprehension; $Pr(z \geq 1.37) = 0.09$.

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[1] Gates, A. Q. Sex difference in reading ability. The Elementary School Journal, 1961, 61, 431-434.

[2] Wyatt, N. M. Sex differences in reading achievement. Elementary English, 1966, 43, 596-599.

The only significant difference, at the 0.05 level, was found in the word-list scores. The scores in the matrix and comprehension sections, however, were in the expected direction (i.e., girls excelling boys). These results, while by no means definitive, supported the notion that when students were removed from the normal classroom social milieu and placed in the asocial environment of a CAI tutorial system, boys performed as well as girls in overall rate of progress through a reading curriculum. The results also tended to support the idea that in a CAI environment the sex difference was minimized in direct proportion to the emphasis on analysis versus rote memorization in the learning task. The one problem section where the girls achieved significantly higher scores than the boys was the word-list section, which was a paired-associate list-learning task.

Achievement tests. Even though the first year's operation of the system was viewed as an extended debugging process, it was felt that a comprehensive end-of-the-year testing program might yield some interesting insights to the potential impact of the program on overall reading achievement. Accordingly, a battery of tests was assembled to measure achievement in each of the major areas of reading behaviors taught at the first-grade level. Wherever possible, standardized tests of the reading behavior to be evaluated were chosen. In several cases, the tests only approximated what we were trying to measure or were not pure tests of a single reading behavior. As far as could be determined, none of the available test batteries included tests of all the reading behaviors listed above. The tests chosen for the test battery were derived from the following sources: (a) Gates-MacGinitie Reading Test, Primary A, Form 1, 1965 edition; (b) California Reading Test, Lower Primary, Form W, 1957 edition with 1963 norms; (c) Stanford Achievement Test, Reading Sections, Primary 1 Battery, 1964 edition; (d) project-developed tests.

The students in the CAI mathematics program provided an ideal control group. Analysis of the individually administered Stanford Binet I.Q. tests at the beginning of the school year indicated that students in the reading program and students in the mathematics program could be considered as two samples from the same population. The mean I.Q. for the reading group was 92.5 (standard deviation 15.6), and the mean I.Q. for the mathematics group was 91.8 (standard deviation 14.6). Any Hawthorne effect induced by the CAI experience was controlled, since the mathematics students had an equal amount of time on the system, but for a different subject matter. The mathematics students received a traditional program of reading instruction, relying primarily upon the Ginn and the Alyne and Bacon first-grade readers.

Overall results. The results of each of the above tests and their major subsections were examined in a series of three-way analyses of variance (treatment, high/low I.Q., sex). No significant interactions were found in any of the analyses. The expected significant differences on the I.Q. and sex variables were found throughout the tests and were of little interest. The means and standard deviations for each test for both the experimental and control groups are shown in Table 14. With the exception of two cases (Stanford Achievement Test, paragraph reading and total score), the direction of differences between the means is in favor of the experimental group.

TABLE 14

Means and Standard Deviations: Major Test Sections, Reading Project

	Experiment		Control		Significance level
	Mean	S.D.	Mean	S.D.	
Gates[a]					
Vocabulary	41.1	9.26	39.3	9.01	N.S.
Comprehension	39.5	8.93	38.8	9.12	N.S.
Total	38.5	9.07	37.4	9.02	N.S.
C.A.T.[a]					
Vocabulary	45.9	1.76	38.1	2.02	$p < 0.01$
Comprehension	41.4	2.51	40.6	2.16	N.S.
Total	45.6	0.58	39.6	1.01	$p < 0.01$
S.A.T.[a]					
Word Reading	40.3	4.84	40.0	2.44	N.S.
Para. Reading	36.0	9.73	38.5	4.07	N.S.
Vocabulary	41.7	3.89	40.7	2.05	$p < 0.01$
Word Study	45.9	3.72	44.9	2.50	$p < 0.01$
Total	44.2	5.89	44.6	3.76	N.S.
Project[b]					
Form Class	8.6	5.23	6.4	4.95	$0.01 < p < 0.05$
Vocabulary	17.7	4.16	15.7	4.27	$p < 0.01$
Pronunciation	11.28	10.21	4.94	7.66	$p < 0.01$
Phonetic Discrim.	14.06	20.07	10.63	15.32	$p < 0.01$

[a] Standard scores: M = 50, S.D. = 10

[b] Raw scores

The test battery was divided into two major categories: (a) tests designed to evaluate the goals and linguistic orientation of the CAI program; and (b) tests designed to evaluate outcomes of a quite different approach to initial reading (i.e., the traditional basal reading series approach). Differences between the means of each of the project-developed tests were statistically significant and in one case, the pronunciation test, the differences were fairly dramatic. Statistical significance was also achieved in three of the eight sub-scales of the standardized tests. Two of these sub-scales, the vocabulary section of the California Achievement Test and the word-study skills section of the Stanford Achievement Test, were composed of a series of tests of sub-skills. It was necessary, therefore, to investigate the possibility that large differences on one or two of the sub-skills might exert an influence powerful enough to produce significance in the sub-scale as a whole. Accordingly, the scores on each test of sub-skills were examined in the same three-way analysis of variance as described above. The results may be seen in Table 15. The significance levels held in all four of the sub-skills for the word-study section of the Stanford Achievement Test and in three of the five tests of sub-skills in the vocabulary section of the California Achievement Test.

In the tabulated results of reading behaviors measured in the evaluation program, eight of the nine tests of decoding skills resulted in differences significant at the .05 level in favor of the CAI group, and in six of those eight tests the significance was at the .01 level or beyond. Three of the tests of comprehension at less than the paragraph level resulted in differences in favor of the CAI group significant at the .05 level. No significant differences were found in the tests of comprehension at the paragraph level.

These results were most encouraging for the potential impact of CAI on initial reading since even the fastest student in the first-year program progressed only a small fraction of the way through the first-year curriculum, which was designed with the expectation that the able student would complete approximately 180 lessons in the first year. The top student in the program completed only approximately 22 per cent of the expected total number of lessons. The average student in the group completed only 11 per cent of the total first year's program. No student was exposed to more than five basic patterns: ac; cac; ccac; ic; and cic (where c stood for any consonant and each vowel was specified). A significant increase in performance in 9 out of 10 tests of decoding skills was achieved by this minimal exposure. Since 6 of the 9 tests were commercial standardized tests whose vocabulary and word patterns were not based on the Stanford CAI program, it was assumed that some transfer of learning took place. Transfer of learning was also observed by classroom teachers; particularly by the teacher of the low-maturity group who reported that a noticeable percentage of these students discovered word patterns in their classroom reading and generalized those word patterns in the attack of new words.

TABLE 15

Means and Standard Deviations: Sub-scales, Reading Project

Test	Experiment		Control		Significance Level
	Mean	S.D.	Mean	S.D.	
C.A.T.					
Vocabulary:					
Word Form	18.3	5.13	15.0	5.30	$p < 0.01$
Word Recognition	13.4	4.87	11.7	4.50	$0.01 < p < 0.05$
Opposites	6.2	2.96	5.7	2.70	N.S.
Picture Association	8.2	2.92	6.8	2.26	$p < 0.01$
Letter Recognition	21.2	5.17	20.6	6.20	N.S.
S.A.T.					
Word Study:					
Audio Perception					
Beginning Sounds	9.87	2.71	8.00	2.70	$p < 0.01$
Ending Sounds	8.89	2.77	6.78	3.13	$p < 0.01$
Phonics	10.20	2.54	8.89	2.70	$p < 0.01$
Phonograms	7.28	2.88	6.33	2.18	$0.01 < p < 0.05$

The most consistent results were found in the decoding skills, the area of initial reading handled in greatest detail by the Stanford CAI program. On the other hand, results in the comprehension tests were mixed, with no significant differences being found in tests of paragraph comprehension. Even the fastest student in this year's program failed to reach the level in the lesson materials introducing exercises on the comprehension of connected discourse. As stated earlier in this paper, the comprehension exercises in the Stanford CAI curriculum served more in the nature of data gathering devices than as a well-defined and complex teaching effort.

Analysis of response data (1967-68). From September 1967 to March 1968, students in the Experienced Teacher Fellowship Program on two separate occasions observed and recorded subject behavior and attitudes. Table 16 indicates the results of children's behavior at the CAI terminals during the first set of observations.

The eight basic behavior categories outlined in this table were observed in each child for 5 minutes at the beginning, in the middle, and at the end of a period. During each 5-minute period, the observer checked the type of behavior displayed every 15 seconds. Thus, for the entire sample of 73 students, all behavior was observed a maximum of 20 times during the 5-minute period for a given student. Variable 1 (looking at the scope or projector) represented a desirable behavior while Variables 2 to 8 were relatively undesirable. The table indicates that Variable 1 was predominant with a mean of 17.2 out of a possible 20 for the entire sample. The Maximum and Minimum columns indicate that although at least one student exhibited the desirable behavior only eight times during the observation period, several children exhibited the desirable behavior a near maximum number of times (i.e., 20 times). The means for Variables 2 to 8 indicate a minimal amount of undesirable behavior, which was often caused when the system functioned at a slower than normal rate.

Weekly report. A weekly report provided information about student progress to the teachers and proctors and also served to identify learning difficulties experienced by the students in sufficient detail so that corrective measures were devised and implemented. The information was derived from recorded responses by the students that included the date; relative response time; student identification number; placement in curriculum; actual response coordinates; nature of the response (i.e., correct, wrong, overtime, unidentifiable); latency in making the response; and positions of various switches and contents of various counters used in curriculum sequencing and branching procedures.

The student's rate of progress through the curriculum was dependent on four different branching sequences: (a) repetition within a specific problem type using optimization procedures; (b) repetition of problem types to obtain more practice to pass successive problem types; (c) completion of additional remedial material to compensate for apparent deficiencies in student experience; and (d) the branching to off-line tutorial help given by a teacher. A proctor branched the student to off-line remedial

TABLE 16

Results of Children's Behavior Working at CAI Terminals, Reading Project

Observed behavior	Variable number	Mean	S.D.	S.E. of mean	Sample	Maximum	Minimum	Range
Looking at scope or projector	1	17.1644	3.0185	0.3533	73	20.0000	8.0000	12.0000
Twisting in chair	2	3.8082	2.9705	0.3477	73	14.0000	0.0	14.0000
Watching others	3	1.0274	1.6581	0.1941	73	9.0000	0.0	9.0000
Looking over or under partitions	4	0.0548	0.4682	0.0548	73	4.0000	0.0	4.0000
Playing with keyboard	5	0.0822	0.4331	0.0507	73	3.0000	0.0	3.0000
Playing with light pen	6	0.2466	0.6827	0.0799	73	4.0000	0.0	4.0000
Playing with projector or scope	7	0.0959	0.4461	0.0522	73	3.0000	0.0	3.0000
Looking or making faces in mirrors	8	0.0274	0.1644	0.0192	73	1.0000	0.0	1.0000

help when the CAI system indicated that the student had worked on a single block of problems for more than two days. The off-line remedial help lasted a minimum of one full session and continued on sequential days at the discretion of the teacher.

The sequence of problem types to which the student was exposed each day within any one lesson, and within a week, recorded the path followed by a student through the curriculum.

At the beginning of each daily session the student repeated the initial problem type completed at the close of his last session. Thus, the same problem type commonly occurred twice in sequence--before and after a change in date. The number of problem types encountered each day was noted, and the sum of daily counts for the lesson or for the week was recorded.

The information about student responses provided in the weekly reports was useful in answering the following general questions:

1. Did the student understand the types of responses expected of him?
2. Did the student attend to the task presented him?
3. Did the student experience visual-muscular coordination problems while trying to respond?

Student responses were catalogued into one of four categories: correct responses; anticipated wrong responses, unanticipated or unknown responses; and overtime responses. The fourth category described responses made after the allotted time for the problem type.

The distribution of both overtime and unknown-answer responses suggested different types of difficulties. For example, if a student consistently made strings of unknown responses, it was assumed that he was having difficulty either with muscular coordination or with understanding directions. Similarly, extensive strings of overtime responses suggested that the student did not attend to the task presented him or, again, that he did not understand the instructions. Each week the proctors received overtime and unknown response distribution for each lesson within the week. The distribution of overtime and unknown responses was also sorted for three of the major blocks within the curriculum (word list, matrix, and comprehension).

The optimization routine used in some of the major blocks provided a method to correct and repeat each of the problems missed by a subject until the response to each problem was achieved without assistance. To determine whether or not this procedure facilitated learning, the ratio of the number of original problems missed to the total number of times the problem was attempted was computed. If this ration was 1.00, the student learned with one correction on each problem. Values less than 1.00 indicated that, on the average, the student required more corrections for each original problem missed (e.g., .5 indicated two trials per problem). This ratio was computed, printed, and labeled the coefficient of interaction.

In addition to the coefficient of interaction, the percentage correct on the first unassisted trial for each problem within a problem type was computed and printed. This computation did not consider any responses made while the student was assisted through the correction procedure. Two additional values were computed and printed: (a) the number of problems in the problem type; and (b) the overall proportion correct on the unassisted trials.

Daily report. Data from the daily reports for 1967-68 were assembled to show the relation between the amount of time a student spent on the computer to his progress through the curriculum, which was measured by the number of problem types completed (e.g., screening test, word block, matrix block, sentence initiators, compound words, contractions). A measure of the problem types completed gave a more accurate evaluation of a student's rate of progress, since the problem types covered more nearly equal units of curriculum than did the lessons. A single lesson contained from 4 to 20 different problem types, and a problem type was counted only once. Thus, when a student repeated any part of the curriculum, those repeated problem types were not added to the total of problem types completed. Only main-line problem types were counted; remedial problem types were not considered.

From these daily reports, a weekly summary was compiled that provided the following information for each child: (a) number of minutes on the computer during the week; (b) cumulative time on the computer to date; (c) lesson and PT completed at the end of each week; (d) total PT's completed to date; (e) number of PT's completed during the week.

Figure 10 indicates the progress of three selected students from October 13, 1967 to March 15, 1968. N5 is the student who progressed the farthest. M1 made moderate progress, and J1 showed the least progress. In each case, the line representing rate of progress approximates a straight line. A noticeable change in the rate of progress (slope) was noted as the student moved into Level II (PT 160). The increase in rate shown by J1 at about 600 minutes probably was explained by the practice of proctoring students through the matrix block after they had been working on a matrix block for 2 consecutive days. The data indicate that student rate of progress during this reporting period essentially was linear.

The scatter diagram shown in Figure 11 locates each student by the time spent on the computer and by progress through the curriculum. The diagonal lines from the origin indicate progress rates in minutes per problem type. Eight students progressed at a rate faster than 3 minutes per problem type. The median rate was about 6 minutes per problem type. About 20 per cent of the pupils progressed at a rate slower than 10 minutes per problem type.

The average-time efficiency of the system was also computed. The average time spent on the computer per day, the number of minutes spent on the computer for each session was totalled for the week and divided by the number of student days; 2 minutes or more of work was counted as

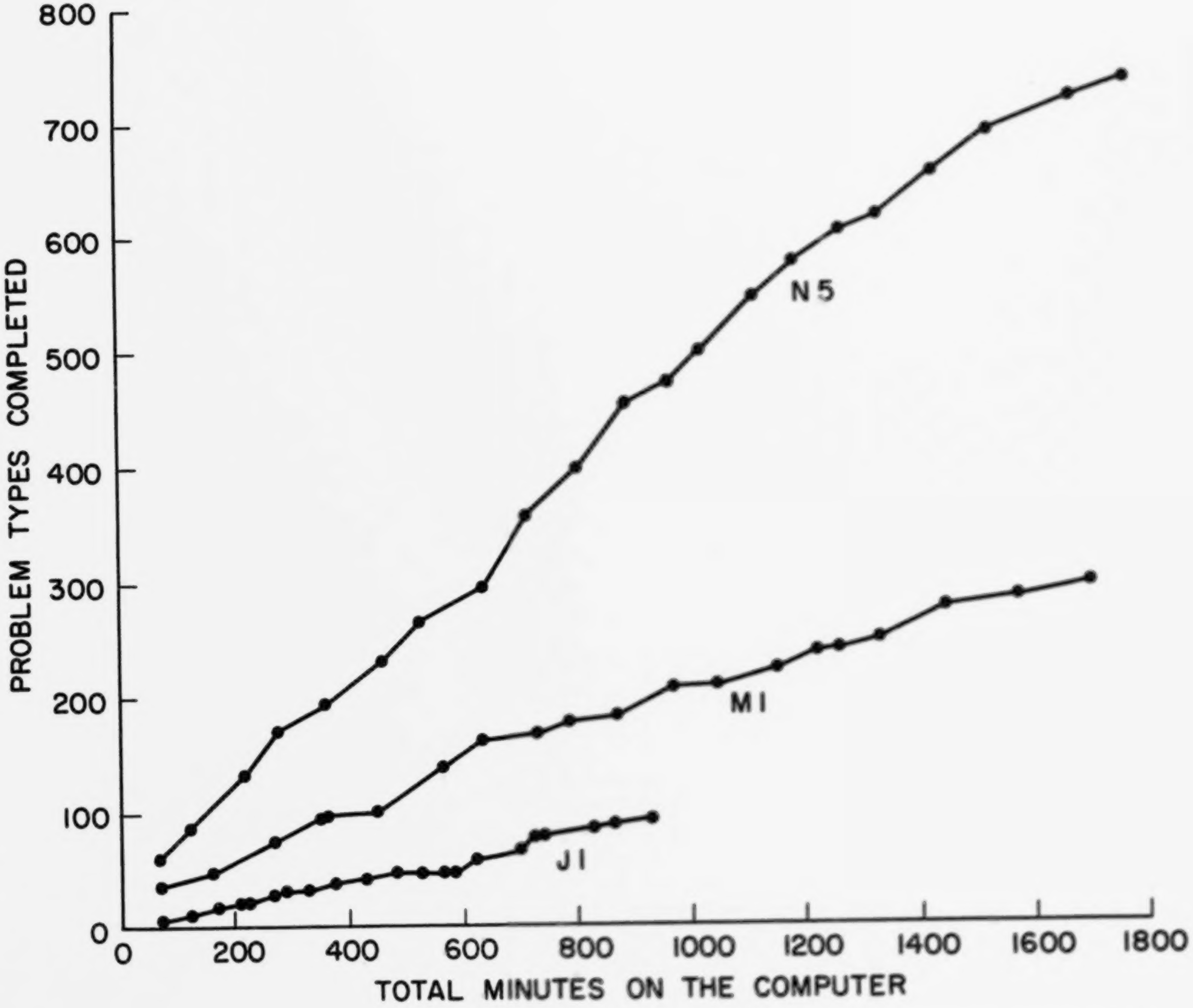

Fig. 10. Weekly Progress of Three Students Through the Reading Curriculum, October 13, 1967 to March 15, 1968

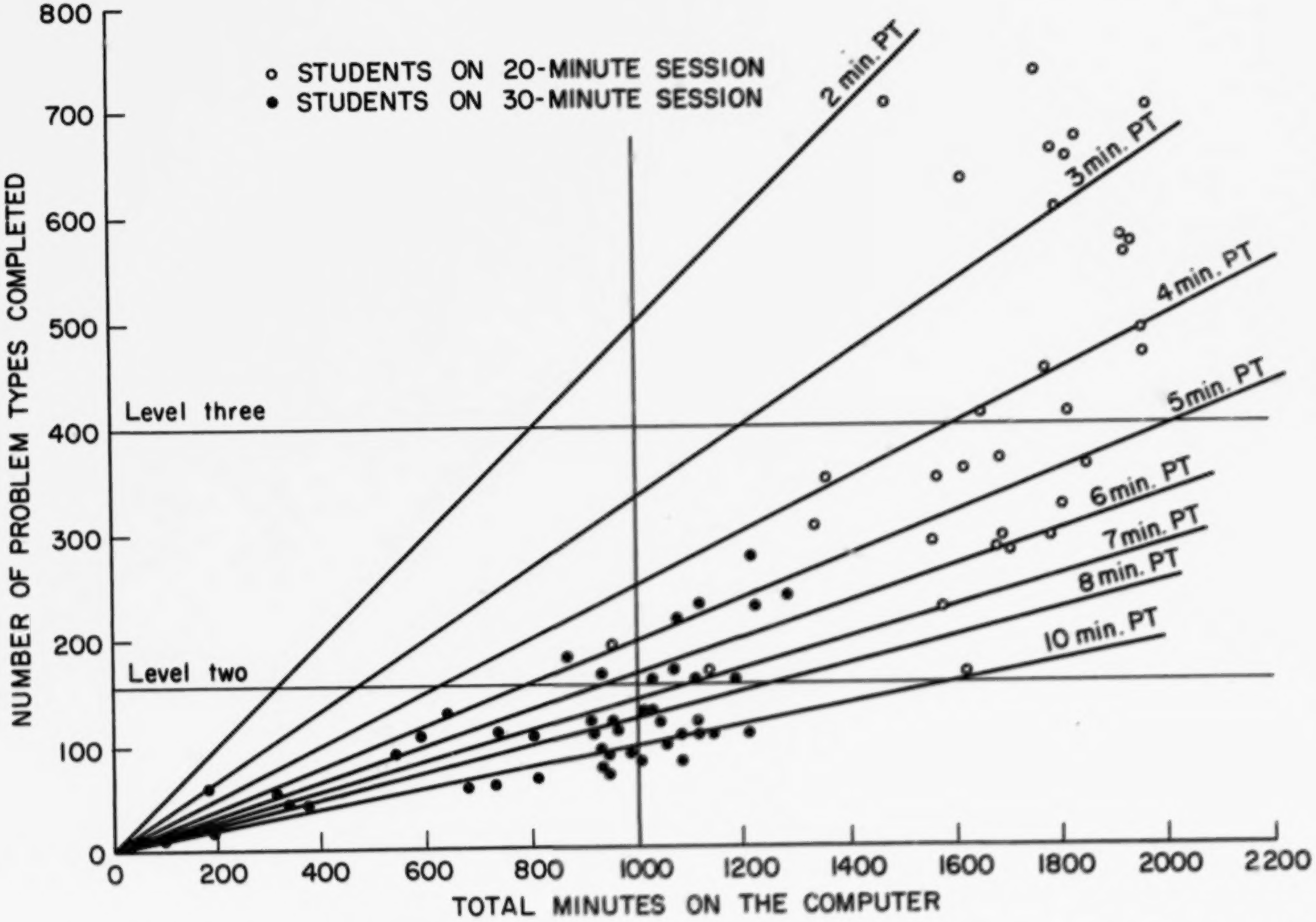

Fig. 11. Distribution of Students by Reading Lesson Material and Time on Computer as of March 15, 1968

a student day. Days when the student was off-line for remedial help and days when machine failure resulted in no time on the computer were not counted. The time efficiency of the system proved to be about 70 per cent with a range from 50 to 80 per cent. Time was lost through machine failure during a session, lesson turn-around time, and interruptions for discipline or explanation.

Chapter 5

Computer-based Instruction in Spelling

5.1. Introduction

The purposes of this project were to investigate how computer-based spelling should be taught and to gain insight into how spelling and similar verbal tasks are learned. Further, techniques for optimal individualization for both lesson content and student feedback to increase the influence of the child's response history on instruction were to be examined.

Groen and Atkinson (1966)[1] stated that mathematical models of the learning process could determine what part of the response history to use for optimization by applying theoretical assumptions in a systematic way. Dear, et al (1967),[2] derived an optimal strategy from the one-element model of paired-associate learning for this purpose.

In this project, spelling was treated as a problem for the one-element model of paired-associate learning. Briefly, the one-element model assumes the subject to be either in the conditioned state or the unconditioned state with respect to a stimulus item. A correct response will occur, with probability 1, when the subject is in the conditioned state. A correct response may occur, with some probability "g," when the subject is in the unconditioned state and guesses correctly. Any incorrect response is produced, with probability "1-g," only when the subject is in the unconditioned state. With a certain constant probability, an individual moves from the unconditioned to the conditioned state on any correct trial. No changes in state take place unless the item is presented. While the states in this model are unobservable, the model can predict certain patterns and parameters in subject performance. Following this assumption and a theorem developed by Karush and Dear (1966),[3] Dear, et al, developed this set of rules used in their paired-associate learning experiment.

1. Administer any item in a presentation set to the subject at the first trial.
2. At the next trial after a subject's incorrect response to an item, present that item to him again.

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[1] Groen, G. J., & Atkinson, R. C. Models for optimizing the learning process. Psychological Bulletin, 1966, 66, 309-320.

[2] Dear, R. E., et al. An optimal strategy for the presentation of paired-associate items. Behavioral Science, 1967, 12, 1-13.

[3] Karush, W., & Dear, R. E. Optimal stimulus presentation strategy for a stimulus sampling model of learning. Journal of Mathematical Psychology, 1966, 3, 19-47.

3. At the next trial after a subject's correct response to the current presentation, present to him the item to which he has made the smallest number of correct responses following his last incorrect response to the item.
4. If several items are eligible under rule 3, select from these the item that has had the smallest number of presentations. If several items are still eligible under this condition, select with equal probability from this set.

This project will follow the Dear, et al, work closely; however, one immediate change will be to interpose one day before repeating items to remove any chance of correct response generation from short-term memory. Students also will work with more difficult material, and a trial-by-trial record of performance will be kept.

5.2. Computer-based Spelling, 1967-68

At the Costano Elementary School, Ravenswood Elementary School District, approximately 60 children participated in the computer-based spelling program working on four teletypes located in a special room at the school. The children reported to the room in groups of 4 and spent from 7 to 12 minutes at the machines. Two separate computer programs were written to execute the experiments.

Lesson Implementation Program (LIP) was the instruction program which presented 16 words to the student each day, monitored and corrected his performance, and returned a record of his performance to the Lesson Optimizing Program (LOP). Because no data analysis tasks were performed simultaneously by the computer while instruction was being offered, a wider and more personal range of computer responses such as "Good work" or "Sorry, you missed it" were incorporated into the program.

Lesson Optimization Program (LOP) analyzed the performance of each student and planned individual successive lessons on the basis of this analysis. Each student's history was kept on counters which recorded total presentations, reinforcements since last error, and total consecutive errors for each word.

No results are available at this time. One major activity of the project to date was the development of necessary software to drive the drills and update student history. Another was the selection and organization of the basic word list. Words were selected from the California State Spelling Series (Madden and Carlson, 1959),[1] grades 3-6 and were ordered by percentage of fifth-grade students spelling an item correctly as listed in the New Iowa Spelling Scale (Greene, 1954).[2]

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[1] Madden, R., & Carlson, T. Success in spelling (California State Series). Sacramento, Calif.: State Department of Education, 1959.

[2] Greene, H. A. The new Iowa spelling scale. Iowa City: State University of Iowa Press, 1954.

Approximately 1,500 words are now available for compilation into individual lists based on pretesting of subjects.

5.3. Concurrent Projects

In addition to these major activities, two other activities were begun. The activities concerned teacher training on the one hand, and modeling or simulating human spelling behavior on the other. Teacher training involved developing a version of the basic driver that will allow a classroom teacher to gain experience in making the kind of detailed decision demanded by computer-based instruction.

The second effort was directed at gathering data and testing programs in an attempt to simulate a "speller" on the computer and also to develop a method of analyzing spelling errors in an attempt to define a consistent pattern for an individual.

Chapter 6

The Kentucky Hook-up

Amendment 1 to the contract authorized the purchase and installation of the following teletype equipment at Morehead State University, Morehead, Kentucky: 1 DEC PDP-8 Computer, 1 DEC 681 Data Line Interface, 1 DEC 685 Serial Line Multiplexer, 1 DEC 637 Bit Synchronous Communication System, 1 DEC 682 Teletype Connection Panel, and 32 W750 Teletype Line Units, with a corresponding configuration at Stanford University.

On May 2, 1967, 30 teletypes were delivered to Breckenridge School (a laboratory school at Morehead State University), and 2 teletypes were delivered to the Elliotsville School. Two PDP-8-680 systems were delivered and accepted at the Stanford Laboratory. Initial PDP-8 programming, the PDP-8/PDP-1 hardware interface, and modifications of PDP-1 software were completed with both PDP-8's operating at Stanford. One PDP-8 was then shipped to Morehead for final installation and debugging. After initial delays in installation of the leased telephone line between Stanford and Morehead, routine on-line operation with 27 teletypes began June 19. This initial operation provided for multiplexing teletype input and output over a single high-grade line, simultaneous use of the PDP-8's console teletypes as an intercom link between Stanford and Kentucky, and a remote PDP-8 program loading from Stanford over the phone line. The PDP-8 programs were edited and assembled using the PDP-1 time-sharing system and loaded directly into the core memory of the local PDP-8.

Portable teletypes with acoustic couplers were used through the two data-phone connections to the PDP-1, allowing access to the computer from any ordinary telephone. Two such teletypes were used daily in Morehead through May and June until operations were shifted to the PDP-8 multiplex system.

By the end of May, grades 1 through 6 at the Breckenridge School and grades 3 through 6 at the Elliotsville School were working on drill-and-practice lessons in elementary mathematics. During the summer session, Breckenridge School used the drill materials for grades 2 through 9. Rowan Country School used the drill materials for grades 2 through 6 and the Upward Bound Program used grade-9 lessons. An adult education program used drills for grades 5, 6, and 9. In addition, a teacher-aid program used grade-5 lessons.

Chapter 7

Dissemination of Information

Three means of information dissemination evolved during the period of the contract: (a) publications and lectures; (b) films; and (c) visitors to the Laboratory. It should be pointed out that the total area of dissemination came about solely by public demand, and not by the Institute seeking publicity.

7.1. Publications and Lectures

Staff members at the Institute wrote a large number of articles for publication as technical reports, for publication in scholarly journals and popular magazines; they also gave lectures and participated in panel discussions and conferences throughout the nation and the world. Appendix 1 gives a listing of publications and lectures.

7.2. Films on the Stanford-Brentwood Project

In accordance with Amendment 1 which extended the period of the contract from June 30, 1967 to December 31, 1967, three films were produced about the Stanford-Brentwood Computer-assisted Instruction Laboratory, and presently available through the Institute for Mathematical Studies in the Social Sciences are the following:

"The Brentwood Project," a 14-minute, 16mm color-sound film devoted exclusively to the Stanford-Brentwood CAI Laboratory, was produced by an Institute staff member in the Communication Department at Stanford University. The film presents a thorough survey of the laboratory operation, the mathematics and reading curricula, the computer system and its function, lesson preparation, the role of proctors, and evaluation of data.

"Please Type Your Name," a 14-minute, 16mm color-sound film produced for the Institute by Davidson Films of San Francisco, is an overview of CAI through research projects conducted by the Institute. The film gives brief descriptions of the teletype logic program, the McComb mathematics project, the computer-assisted Russian course at Stanford University, and the Stanford-Brentwood CAI Laboratory.

"Computers in the Classroom," a 5-minute, 16mm color-sound film produced by ABC for the IBM Corporation, is a very brief description of the Stanford-Brentwood Laboratory, and includes a short interview with Professor Patrick Suppes.

These films were (a) used to supplement talks given by staff members; (b) sold to interested individuals and institutions at cost; (c) loaned to individuals and institutions for a nominal fee, and loaned to television stations for broadcast; (d) duplicated at cost for film and television producers to use in documentaries about CAI.

7.3. Visitors

The number of visitors to the Laboratory from January to December, 1967 demonstrated an increased awareness of the project by the public, professional educators, and news media throughout the nation and the world. Owing to the limited viewing area and the large number of visiting requests, it was necessary to preschedule all visits. Generally, groups were limited to 10 persons. In order to accommodate the wide range of interests (from data reduction to curriculum details), it was necessary that various Institute staff members be on hand to insure the dissemination of accurate and authoritative information.

A special terminal equipped with a loudspeaker audio output served as a demonstration unit for small groups. Visitors during the mathematics instructional time were allowed to work through lessons actually on-line for the children. Multiple lessons also were available so that the visitor was able to view different sections of the instructional program.

Visitors who appeared during the reading instructional sessions received a special overview demonstration lesson on first-grade CAI reading curriculum. The following is an abstract of that course.

NAME: READ1-52 (Code Name: BZ)
TIME: 10 minutes to over two hours (user determined)
LENGTH: 240 sectors on an IBM 2315 disk pack (about 7,000 instructions)
MACROS: 52
FUNCTIONS: 7
AUDIO MESSAGES: 335 (1-20 seconds; many segmented audios)
FILM FRAMES: 26
GRAPHICS: 41
FREE-CHOICE POINTS: 26 (some may be encountered more than once)
SECTIONS WITHIN THE LESSON: 21, including major sub-sections; otherwise, 17
RESTART POINTS: 1
TERMINAL EQUIPMENT: CRT with light pen, rear-image projector, audio headset
MODE OF RESPONSE: Light pen (multiple choice)
TOTAL PREPARATION TIME: Four months
AUTHORS: David McMullen and Karl Anselm

This learner-controlled program described and demonstrated numerous capabilities of CAI: branching; student feedback; functions; graphics; and proctor calls. It used the following terminal equipment: cathode-ray tube (CRT); light pen; image projector; and audio unit.

After assistance in signing on, the user required no outside help. No knowledge of computers, the reading curriculum, or previous acquaintance with CAI was assumed or was necessary to use this program. The course was intended for parents, classroom teachers, curriculum writers, researchers, and computer personnel, as well as others interested in this mode of instruction.

The basic outline of the course was as follows:

Welcome: demonstrated use of the light pen and audio system
Day 1: demonstrated graphics and answering on the CRT
Day 2: demonstrated correction procedures and the image projector
Day 3: letter-teaching sequences
Introduction: standard lesson outline
Word Block: initial teaching of words and optimization routine
Poem: demonstrated intonational material
Matrix: major device for presenting linguistic patterns
Screening Test: the standard beginning for a lesson
Game: adapted baseball to reading instruction
Doggerel: introduced comprehension section
Usage: comprehension as understanding definitions
Form-Class: comprehension as correct use of syntax
Who-What: comprehension as ability to answer questions
Reading Story: read by student (audio as needed)
Polysyllabic Section: demonstrated teaching of two-syllable words
Conclusion: allowed user to return to beginning of lesson and review.

Unlike a child's lesson, the user was able to choose sections of a lesson he wished to see. Before each section, he was given an opportunity to bypass a section or to continue through it. At the end of the lesson, the user was able to return to the beginning of the lesson and then to bypass material until he came to a section he wished to review. The one restart point at the beginning of the lesson enabled the user to sign off at any time and to sign on at the start of the program. The course proved particularly valuable through its inclusiveness and user-control aspect.

System records were kept of those who have visited the Laboratory. A complete list of visitors during January 1 through March 31, 1967; October 1 through December 31, 1967; and January 1 through March 31, 1968 is included in Appendix 2, together with a list of the foreign countries represented.

In addition to regular visitors, several filming groups visited the Laboratory. A KQED-TV "Education in Motion" series presented a program on the relationship of the Laboratory to the classroom teacher's program. The KQED-TV "Do You Read Me?" series presented a program on innovative instructional procedures developed at Brentwood for the teaching of reading. An IBM documentary team showed the relationship of the equipment to the instructional program; and Information Management Facilities, Inc., prepared a film sequence of children working with the terminal equipment, which was used in an IBM seminar and then was made available to groups from many fields, including education, science, industry, the arts, government, and religion.

During the second year of operation, public opinion gradually changed from one of concern of replacing teachers by this technology to an interest in its proven feasibility, its successes, and implications for school systems preparing for a future which included computer-assisted instruction.

Chapter 8

Conclusions

Areas of research investigated in this report, which is a supplement to Final Report OE 5-10-050, include the continued development of a computer-assisted instruction program in mathematics and initial reading at the Brentwood Elementary School, a new investigation of computer-based instruction for spelling at Costano Elementary School, and the initiation of a CAI program in elementary-school mathematics for children in rural Kentucky through provision of necessary teletype equipment and drill-and-practice curriculum materials.

8.1. Mathematics and Reading

The theory of individualized instruction developed at Brentwood through experimentation with the mathematics and reading programs can, with proper constraints, be generalized to other programs such as elementary science and beginning work in foreign languages. This theory of instruction attempts to optimize the learning situation by manipulating variables such as content, nature and sequence of presentation, to provide the best learning environment for each individual child. To achieve individualization, a means for determining the best future program of instruction for each child based on the history of his past responses was required. Presentation of materials for each child was controlled by correctness of his past responses, the length of time he took to make them, and the nature of his past learning patterns.

Thus, the interaction between computer and student is that of a patient tutor. The individualized curriculum design offered a challenge to the bright child by allowing him to accelerate at his own pace, while the slower student, through added remedial exercises, could also feel a sense of accomplishment. The full potential and applicability of computers in education are far from realization. The work at Brentwood under controlled laboratory conditions offers a beginning to generalize concepts and skills important in teaching and learning throughout education.

A more detailed statement of plans of the Brentwood part of the contract may be found in the conclusions given as part of Final Report OE 5-10-050.

8.2. Spelling

A new experiment designed to investigate how computer-based spelling should be taught and to gain insight into how spelling and similar verbal tasks are learned was started. Concurrently, techniques for optimal individualization for both lesson content and student feedback to increase the influence of the child's response history on instruction were to be examined. Approximately 60 children from the Costano Elementary School, Ravenswood Elementary School District, participated in the program. The children reported to the teletype room, which contained four teletypes, in groups of 4 and spent from 7 to 12 minutes at the machines. Two separate computer programs were written to execute the experiments. The Lesson Implementation Program (LIP) was the instruction program and presented 16 words to the student each day, monitored and corrected his performance, and returned a record of his performance to the Lesson Optimizing Program (LOP). No data analysis tasks were performed by this program. The Lesson Optimization Program analyzed the performance of each student and planned individual successive lessons on the basis of this analysis. Each student's history was kept on counters which recorded total presentations, reinforcements since last error, and total consecutive errors for each word. Additional activities under this project were the development of necessary software to drive the drills, updating of student history, and the selection and organization of the basic word list. Further plans included a teacher-training program that involved developing a version of the basic driver that would allow a classroom teacher to gain experience in making the kind of detailed decision demanded by computer-based instruction, and an attempt to simulate a "speller" on the computer, including a method of analyzing spelling errors to define a consistent pattern for an individual.

8.3. Morehead, Kentucky

On May 2, 1967, 30 teletypes were delivered to Breckenridge School (a laboratory school at Morehead State University, Kentucky) and 2 teletypes were delivered to Elliotsville School, Morehead, Kentucky. Supporting teletype equipment for both Morehead and Stanford was included. By June 19, 1967, routine on-line drill and practice in elementary mathematics began.

By the end of May, grades 1 through 6 at the Breckenridge School and grades 3 through 6 at the Elliotsville School were working on drill-and-practice in elementary mathematics. During the summer session, Breckenridge School used the drill materials for grades 2 through 9. Rowan County School used the drill materials for grades 2 through 6 and the Upward Bound Program used grade-9 lessons. An adult education program used drills for grades 5, 6, and 9. In addition, a teacher-aid program used grade-5 lessons.

There was not sufficient time during the period of the contract to make a behavioral evaluation of student performance. The primary purpose of the project was to attempt the installation of a system such as this in a rural area. Thus, the problem was one of operational feasibility rather than behavioral feasibility. The experience of the several months of operation indicated that there were no really different problems encountered in operating in a rural area rather than an urban area. Certainly the student response was at least as positive, if not more so.

Appendix 1

Publications and Lectures

Publications

Richard C. Atkinson

Reading instruction under computer control. *American School Board Journal*, 1967, *155*, 16-17.

Learning aspects of computer-assisted instruction. In R. W. Gerard (Ed.), *Computers and Education*. New York: McGraw-Hill, 1967. Pp. 11-63.

Instruction in initial reading under computer control: The Stanford Project. *Journal of Educational Data Processing*, 1967, *4*, 175-192.

Computer-based instruction in initial reading: A progress report on the Stanford Project. Technical Report 119, August 25, 1967, Institute for Mathematical Studies in the Social Sciences, Stanford University (with H. A. Wilson).

Computerized instruction and the learning process. Technical Report 122, September 15, 1967, Institute for Mathematical Studies in the Social Sciences, Stanford University.

Patrick Suppes

Mathematical concept formation in children. *American Psychologist*, 1966, *21*, 139-150.

Tomorrow's education. *Education Age*, 1966, *2*, 4-11.

Towards a behavioral psychology of mathematical thinking. In J. Bruner (Ed.), *Learning about Learning* (a Conference Report). Washington: U. S. Government Printing Office, 1966. Pp. 226-234.

The psychology of arithmetic. In J. Bruner (Ed.), *Learning about Learning* (a Conference Report). Washington: U. S. Government Printing Office, 1966. Pp. 235-242.

Accelerated program in elementary-school mathematics--the second year. *Psychology in the Schools*, 1966, *3*, 294-307.

The axiomatic method in high-school mathematics. *The Role of Axiomatics and Problem Solving in Mathematics*. The Conference Board of the Mathematical Sciences, Washington, D. C.: Ginn, 1966. Pp. 69-76.

Plug-in instruction. *Saturday Review*, July 1966, pp. 25, 29, 30.

The uses of computers in education. *Scientific American*, September 1966, 206-221. Reprinted in *Information, A Scientific American Book*. San Francisco: W. H. Freeman, 1966. Pp. 157-174. (German translation Anwendungen elektronischer Rechenanlagen in Unterricht. In *Information Computer und künstliche intelligenz*. Frankfurt am Main: Umschau Verlag, 1967. Pp. 157-172.)

Some models for response latency in paired-associates learning. *Journal of Mathematical Psychology*, 1966, *3*, 99-128. (with G. Groen and M. Schlag-Rey)

Arithmetic drills and review on a computer-based teletype. *Arithmetic Teacher*, April 1966, 303-309. (with M. Jerman and G. Groen)

On using computers to individualize instruction. In D. D. Bushnell and D. W. Allen (Eds.), *The Computer in American Education*. New York: Wiley, 1967. Pp. 11-24.

The psychological foundations of mathematics. *Les Modèles et la Formalisation du Comportement*. Colloques Internationaux du Centre National de la Recherche Scientifique. Editions du Centre National de la Recherche Scientifique. Paris: 1967. Pp. 213-242.

Applications of mathematical models of learning in education. In H. O. A. Wold (Scientific Organizer), *Model Building in the Human Sciences*. Entretiens de Monaco en Sciences Humaines, Session 1964. Monaco: Union Europienne D'Editions, 1967. Pp. 39-49.

The case for information-oriented (basic) research in mathematics education. In J. M. Scandura (Ed.), *Research in Mathematics Education*. Washington, D. C.: NCTM, 1967. Pp. 1-5. (with G. Groen)

Some counting models for first-grade performance data on simple addition facts. In J. M. Scandura (Ed.), *Research in Mathematics Education*. Washington, D. C.: NCTM, 1967. Pp. 35-43. (with G. Groen)

Experiments in second-language learning. New York: Academic Press, 1967. (with E. Crothers)

Foundations of stimulus-sampling theory for continuous-time processes. *Journal of Mathematical Psychology*, 1967, *4*, 202-225. (with J. Donio)

Some problems in the geometry of visual perception. *Synthese*, 1967, *17*, 173-201. (with F. Roberts)

Computer-based instruction. *Electronic Age*, 1967, *26*, 2-6.

The teaching machine. *Christian Science Monitor*, August 10, 1967, p. 11.

Linear structural models for response and latency performance in arithmetic on computer-controlled terminals. In J. P. Hill (Ed.), Minnesota Symposia on Child Psychology. Minneapolis: Univ. Minn. Press, 1967. Pp. 160-200.

Some theoretical models for mathematics learning. Journal of Research and Development in Education, 1967, 1, 5-22.

Lectures

Karl Anselm

Computer-assisted instruction and the media specialist. Presented at the National Education Defense Act Media Institute, State University of New York, College at Brockport, July 3, 5, 1967.

Computer-assisted instruction and the Stanford-Brentwood CAI reading project. Presented at the National Defense Education Act Reading Institute, State University of New York, College at Brockport, July 6, 1967.

Educational innovation. Presented at the McComb Institute, Stanford University, July 17, 1967.

The Stanford-Brentwood CAI project. Presented at the Institute for Mathematical Studies in the Social Sciences Reading Institute, Stanford University, July 24, July 31, August 7, and August 14, 1967.

Computer-assisted instruction and the classroom teacher. Seminar presented at the Experienced Fellowship Program, Stanford University, August 1, 1967.

Richard C. Atkinson

CAI instruction. Invited talk at the American Educational Research Association Convention, Chicago, Illinois, February 17, 1966.

Seminar on Discrimination and Learning Theory at the Center for the Advanced Study in the Behavioral Sciences, Stanford, California, June 20 - July 30, 1966.

EDUCOM Taskforce Network Meetings, Boulder, Colorado, July 5, 1966.

APA Convention, Psychometric Society Convention, New York, September 2-6, 1966.

Foothill College Faculty Retreat, Asilomar, California, January 6-8, 1967.

International Reading Association Convention, Seattle, Washington, May 4-6, 1967.

Course on Perception and Learning, University of California, Los Angeles, California, June 5-10, 1967.

Computer-based instruction in initial reading. Lecture presented at City University of New York, July 25, 1967.

Medical center of the 21st century. Seminar given at the Edith Meyers Auditorium of the Children's Hospital Medical Center, Oakland, California, October 6, 1967.

International Book Fair, Frankfurt, Germany, October 11-25, 1967.

Recognition versus recall: Storage or retrieval differences. Invited address at The Psychonomic Society 8th Annual Scientific Meeting, October 26, 1967. (with R. Freund)

Computerized instruction and the learning process. Invited talk at the Educational Testing Service Meetings, New York City, New York, October 28, 1967.

CAI: theory and applications. Invited talk at the University of Chicago, School of Education, Chicago, Illinois, October 30, 1967.

Computerized instruction and the learning process. Lecture presented at the American Psychological Association Meeting, Washington, D.C., September 1-5, 1967.

Models for optimizing the learning process. Lecture presented at the Institute of Electrical and Electronics Engineers, Los Angeles, California, September 27, 1967.

Some two-process models for learning and memory. Invited talk at the University of Chicago Colloquium, Mathematical Biology Group, Chicago, Illinois, October 31, 1967.

Teaching children to read under computer control. Seminar in Bio-Behavioral Sciences, Stanford Medical Center, Stanford, California, November 14, 1967.

What makes Johnny learn. CACER Annual Conference on Education Research, San Diego, California, November 15-16, 1967.

Models for short-term memory. Seminar presented at the Psychology Department, University of Toronto, January 23, 1968.

Computer application in teaching. Lecture presented at the Ontario Institute for Studies in Education, Graduate Department, School of Education, University of Toronto, January 23, 1968.

Computerized instruction and the learning processes. Invited lecture presented at the Educational Research and Development Council, University of Minnesota, Minneapolis, Minnesota, January 25, 1968.

L. D. Berkowitz

Computer-based instruction in arithmetic (the drill-and-practice program). Lecture presented at National Council of Teachers of Mathematics, Houston Meeting, Houston, Texas, November 25, 1967.

Computer-based instruction in arithmetic (the drill-and-practice program). Lecture presented at Seminar in CAI, School of Education, Stanford University, January 24, 1968.

Jamesine E. Friend

Addition and subtraction via computer-assisted instruction. Presented at the Joint Meeting of the Oregon Council of Teachers of Mathematics and the Northern Section of the California Mathematics Council, Weed, California, October 7, 1967.

The Stanford-Brentwood Project. Presented at the November meeting of the Scientific Research Society of America, Sequoia Branch, Palo Alto, California, November 30, 1967.

Addition and subtraction via computer-assisted instruction. Presented at the Fall Conference of the California Mathematics Council, Northern Section, Asilomar, California, December 8, 1967.

Mathematics at Brentwood. Lecture presented at seminar on Computer-assisted Instruction, Stanford University, Stanford, California, January 31, 1968.

Max Jerman

Computer-assisted instruction, the drill-and-practice program. Lecture presented at the Madison Project Summer Workshop for Teachers, Bird School, Chicago, Illinois, July 11-12, 1967.

(1) Computer-assisted instruction, the drill and program. (2) Review of research in programmed instruction. (3) Preparing objectives for programmed instruction. (4) Preparing objectives for programmed instruction. Lectures presented at the McComb Institute, Stanford University, Stanford, California, July 17-20, 1967.

Computer-assisted instruction, the drill-and-practice program. Lecture presented to the Shell Merit Fellows, Stanford University, Stanford, California, July 19, 1967.

Computer-assisted instruction, the drill-and-practice program. Lecture and demonstration presented to the McComb teachers, McComb, Mississippi, September 20, 1967.

Computer-assisted instruction, the drill-and-practice program. Lecture and demonstration presented to administrators, Magnolia, Arkansas, September 21, 1967.

Computer-assisted instruction in arithmetic. Presented at the Annual Meeting of the Idaho State Teachers of Mathematics, Boise, Idaho, October 12, 1967.

Using the computer for research in education. Presented at the Annual Meeting of the Idaho State Teachers of Mathematics, Boise, Idaho, October 13, 1967.

Computer-assisted instruction, the Stanford project. Lecture and demonstration at the Annual Meeting of the National Science Teachers, Claremont Hotel, Berkeley, California, October 26-27, 1967.

Computer-assisted instruction. Lecture and demonstration presented to ESEA Title III Directors of Vicksburg, Mississippi, December 6-7, 1967.

The uses of time-sharing systems. Presentation as a panel member at the annual meeting of COMMON, Sheraton-Palace Hotel, San Francisco, California, December 12, 1967.

Workshop in Computer-assisted Instruction conducted at Morehead State University, Morehead, Kentucky, February 1-3, 1968.

Patrick Suppes

Programs in new mathematics for the elementary school. Public Lecture, Cornell University, Ithaca, New York, January 13, 1966.

(1) Computer-assisted mathematics instruction in the schools, (2) Mathematical mind of the elementary-school child, (3) Geometric concepts in the junior-high school. Alamo District Council of Teachers of Mathematics, National Council of Teachers of Mathematics, Trinity University, San Antonio, Texas, February 4-5, 1966.

The use of computers in instruction. Association for Computing Machinery, Sunnyvale, California, February 17, 1966.

Using computers to teach elementary-school mathematics. 1966 Regional Meeting, National Council of Teachers of Mathematics, Washington, D.C., March 5, 1966.

Teaching children with computers. Santa Clara Valley Mathematics Association, April 22, 1966.

Tomorrow's education. Summer University of Finland, Vasa, Finland, (3 lectures), June 27-29, 1966.

On learning new mathematics. Radio phone hookup, San Francisco, California, August 18, 1966.

Electronic individualization of instruction. Pre-school Workshop for School Administrators in the Greater San Diego Area, San Diego, California, August 24, 1966.

Logical and mathematical concept formation in children. Symposium on cognitive development in children, American Psychological Association, New York, September 4, 1966.

Report on Stanford-Brentwood CAI Laboratory. California State Board of Education, Los Angeles, California, September 8, 1966.

CAI in elementary-school mathematics. Institute of Human Learning Graduate School, Florida State University, Tallahassee, Florida, September 18, 1966.

CAI teaching techniques and equipment. The Institute of Electrical and Electronics Engineers, Stanford, California, September 27, 1966.

The Stanford Project. Conference on Coordination of Curriculum Studies, sponsored by USOE and NSF, Chicago, Illinois, October 14, 1966.

Concept learning. Discussant, Symposium on research approaches to the learning of school subjects, sponsored by Phi Delta Kappa and School of Education, University of California, Berkeley, California, October 28, 1966.

The promise of the computer. TV Symposium, KQED, Channel 9, San Francisco (one-hour panel shown in conjunction with the Fall Joint Computer Conference), November 7, 1966.

Prospects for computers in education. Fall Joint Computer Conference, San Francisco, California, November 8, 1966.

Computers and children. Fall Joint Computer Conference, San Francisco, California, November 9, 1966.

Impact of technology in the elementary school. Elementary Principals' Association, Southern Nevada Vocational-Technical Center, sponsored by Las Vegas Clark County School District, Las Vegas, Nevada, November 14, 1966.

New trends in education. Nevada Southern University, sponsored by Las Vegas Clark County School District, Las Vegas, Nevada, November 14, 1966.

CAI in mathematics. Valley High Schools, Southern Nevada Mathematics Council, sponsored by Las Vegas Clark County School District, November 14, 1966.

Future of computers in education. Committee for Economic Development, New York, November 17, 1966.

CAI Board Meeting of the Human Factors Society and the Society for Information Display, Palo Alto, California, December 13, 1966.

The computer in the classroom. Service Committee on Public Education, San Francisco, California, January 11, 1967.

Teaching children with computers. Walter Hays Elementary School Parent Meeting, Palo Alto, California, January 18, 1967.

On using computers to teach elementary mathematics. 38th Annual Mid-year Education Conference, Colorado State College, Greeley, Colorado, January 27, 1967.

Where we are with the computer in our schools. Ravenswood Teachers' Association, Brentwood Elementary School, East Palo Alto, California, January 30, 1967.

The computer age. Radio of New York Worldwide, Inc., New York City, New York (radio interview), February 16, 1967.

CAI lecture and demonstration. Fifth Annual Committee on Education, Data Systems, Off. of Educ. Conf., Hotel Utah, Salt Lake City, Utah, April 11, 1967.

Computer-based instruction in elementary mathematics. State Supervisors Annual Meeting, State Supervisors of Mathematics, Las Vegas, Nevada, April 17, 1967.

Mathematics and stimulus response theories of learning. Speaker, General Session, National Council of Teachers of Mathematics, Las Vegas, Nevada, April 20, 1967.

Individualizing arithmetic instruction by using computers. Seminar, National Council of Teachers of Mathematics, Las Vegas, Nevada, April 20, 1967.

Current and future applications of computers in education. Association for Computing Machinery, Palo Alto, California, May 4, 1967.

Computer-assisted instruction. Colloquium, Department of Computer Science, Stanford, California, May 23, 1967.

CAI--current and future. National Society for Information Display, Jack Tar Hotel, San Francisco, California, May 24, 1967.

On-line computer instruction. Commonwealth Club, San Francisco, California, June 20, 1967.

The logic of scientific theories. Lecture presented at the NSF Institute in the Philosophy of Science, Stanford University, June 26 - August 4, 1967.

CAI. Participant, Workshop on Flexible Scheduling, Summer Programs in Secondary Education, Stanford University, July 17, 1967.

Education for what. Keynote Speaker, Annual Meeting of Mt. Diablo Unified School District, Concord, California, August 31, 1967.

Teaching with computers. Television appearance on KCET, Channel 28, Los Angeles, California, October 9, 1967.

What we know and don't know about how students learn elementary mathematics. Lecture presented at Annual State Convention, Oklahoma City, October 23, 1967.

Using computers to teach elementary mathematics. Lecture presented to the Oklahoma Council of Teachers of Mathematics, Oklahoma City, Oklahoma, October 23, 1967.

Aspects of computer-assisted instruction in elementary mathematics. Lecture presented to Missouri State Teachers Association (MCTM), St. Louis, Missouri, November 3, 1967.

Are the humanities obsolete? Lecture presented at Symposium for Philosophical Studies, Case Institute of Technology, Cleveland, Ohio, November 10, 1967.

CAI in elementary mathematics. Lecture presented at meeting of Teachers Association, Shreveport, Louisiana, November 21, 1967.

Meeting the diverse needs of students. Lecture presented at Mathematics Conference, Mathematics Curriculum for an Urban School Population, Chicago Board of Education, Chicago, Illinois, December 8, 1967.

CAI in elementary mathematics. General Session, Conference of State Supervisors of Mathematics on Computers and Mathematics Instruction, Department of Mathematics, University of Denver (sponsored by NSF), Colorado, December 9, 1967.

Survey of computer-assisted instruction. Institute for Computer-assisted Instruction, Rickey's Hyatt House, Palo Alto, California, January 16, 1968.

Computer-assisted instruction at Stanford. Lecture presented to Faculty Women Newcomers, Stanford University, Stanford, California, January 18, 1968.

H. A. Wilson

Systems for computer-aided instruction and experimentation. Annual meeting of the American Psychological Association, Washington, D.C., September 2, 1967.

Problems and prospects of computer-assisted instruction. Institute for Computer-assisted Instruction, Swampscott, Massachusetts, November 13-15, 1967.

The Stanford-Brentwood CAI project. Canadian Council for Research in Education, Ottawa, Ontario, November 22-24, 1967.

Computers as an educational media. California Association of School Administrators Conference, panel discussion, San Francisco, California, December 7, 1967.

The Stanford CAI project. Lecture presented at Institute for Computer-assisted Instruction, Palo Alto, California, January 16, 1968.

Appendix 2

Visitors to the Stanford-Brentwood Laboratory

January 1 - March 31, 1967

18	Associations, clubs, foundations (Ford, National Education Association, American Association of University Women)
168	Colleges and universities (presidents, administrators, professors, research specialists)
11	Consultants to education and educational research agencies
166	Corporations, companies, industrial firms (presidents, board chairmen, sales representatives, research specialists)
17	Correspondents and news media (both foreign and domestic)
12	Foreign governmental education offices and agencies
23	Governmental agencies (USOE, Bureau of Indian Affairs, PACE, Job Corps, NIH, NSF, Regional Laboratories, Military)
31	Parents, interested citizens
9	Private and parochial elementary- and secondary-school staff members
223	Public school personnel (elementary- and secondary-school superintendents, principals, teachers, consultants)
14	Publishers (presidents, executive staff members, sales representatives, editors, research specialists)
11	School board members and their committees
34	State and country education departments (superintendents, consultants, research specialists)
174	Students (elementary, secondary, and college)
915	

Foreign countries represented: Belgium, Brazil, Canada, France, Finland, Hong Kong, Italy, Japan, Philippines, Switzerland, Thailand, United Kingdom, and Yugoslavia (Hawaii, Puerto Rico, Virgin Islands).

October 1 - December 31, 1967

4	Architects
9	Associations and foundations (Ford, National Education Association, American Association of University Women)
11	Consultants to educational systems and educational research agencies

97	Colleges and universities (presidents, administrators, professors, research specialists)
114	Corporations, companies, industrial firms (presidents, board chairmen, sales representatives, research specialists)
19	Correspondents, news writers, television and radio personnel (both domestic and foreign)
7	Foreign governmental agencies and education offices
15	Governmental agencies (USOE, Bureau of Indian Affairs, PACE, Job Corps, NIH, NSF, Regional Laboratories, Military--Annapolis, West Point, Air Force Academy, NASA)
117	Parents, interested citizens (100 in special demonstrations)
5	Private and parochial elementary- and secondary-school staff members
2	Public school board members and/or their committees
158	Public school personnel (elementary- and secondary-school superintendents, principals, teachers, consultants, curriculum coordinators, special education teachers)
21	Publishers (presidents, senior vice-presidents, vice-presidents, curriculum specialists, sales representatives, editors, research specialists, executive staff members)
7	State and country departments of education (superintendents, consultants, research specialists, curriculum coordinators)
156	Students (secondary, college, graduate, student teachers)
742	

Foreign countries represented: Argentina, Australia, Belgium, Brazil, Canada, Chile, Colombia, England, France, Germany, Holland, Ireland, Japan, New Zealand, Norway, Philippines, Republic of South Africa, Sweden, and Uruguay.

Filming groups present: KQED-TV "Education in Motion" Series; KQED-TV "Do You Read Me?" Series; IBM Documentary Team; Information Management Facilities, Inc., for IBM.

January 1 - March 31, 1968

10	Architects
80	Colleges and universities (presidents, administrators, professors, research specialists)
141	Corporations, companies, industrial firms (presidents, board members, sales representative, research specialists)
7	Correspondents, news writers, television personnel (both domestic and foreign)
5	Foreign governmental agencies and education offices

27	Governmental agencies (USOE, PACE, Job Corps, Military, NIH)
77	Interested citizens
12	Private and parochial elementary- and secondary-school staff members
9	Public school board members and/or their committees
172	Public school personnel (elementary- and secondary-school superintendents, principals, teachers, consultants, curriculum coordinators, special education teachers, directors of special projects)
18	Publishers (vice-presidents, curriculum specialists, sales representatives, editors, executive staff members)
10	State, county and provincial departments of education
194	Students (college, university, student teachers)
762	

Foreign countries represented: Argentina, Brazil, Canada, Alberta, British Columbia, Ontario, Quebec, Saskatchewan, Chile, Czechoslovakia, France, Germany, Guam, Hawaii, India, Italy, Japan, Malawi, New Zealand, Nigeria, Okinawa, Philippines, Puerto Rico, Switzerland, Sweden, Taiwan, Union of Soviet Socialists Republic, and Uruguay.

Film groups present: ASPEKT Film AB (Swedish Television), Stockholm, Sweden; Davidson Film Company, San Francisco; Encyclopedia Brittanica Films, Inc.